



**CHARACTERIZATION AND POTENTIAL BIOLOGICAL CONTROL AGENT
AGAINST WHITE ROOT ROT PATHOGEN (*Rigidoporus microporus*) IN
RUBBER TREE (*Hevea brasiliensis* Müll. Arg.)**

GO WEN ZE

FPAS 2020 1



**CHARACTERIZATION AND POTENTIAL BIOLOGICAL CONTROL AGENT
AGAINST WHITE ROOT ROT PATHOGEN (*Rigidoporus microporus*) IN
RUBBER TREE (*Hevea brasiliensis* Müll. Arg.)**

By

GO WEN ZE

**Thesis Submitted to the School of Graduate Studies, Universiti Putra
Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of
Philosophy**

December 2019

All material contained within the thesis, including without limitation text, logos, icons, photographs and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia



DEDICATION

Special dedicated to:

My supervisory committees
Assoc. Prof. Dr. H'ng Paik San
Prof. Dr. Luqman Chuah Abdullah
Prof. Dr. Wong Mui Yun
Assoc. Prof. Dr. Tan Geok Hun
Dr. Salmiah Ujang

My grandfathers
Late Mr. Go Ting Ge
Mr. Ng Siew Khoon

My parents
Mr. Go Heng Her
Mdm. Ng Swee Chai

And

My Siblings
Mr. Go Jie Xian
Ms. Go Wen Ying
Mr. Go Jie Peng

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

CHARACTERIZATION AND POTENTIAL BIOLOGICAL CONTROL AGENT AGAINST WHITE ROOT ROT PATHOGEN (*Rigidoporus microporus*) IN RUBBER TREE (*Hevea brasiliensis* Müll. Arg.)

By

GO WEN ZE

December 2019

Chairman: H'ng Paik San, PhD
Faculty: Forestry

Rubber is the second most important commodity in Malaysia which grown primarily for the production of latex. Unfortunately, a major issue faced by majority of the rubber growing countries, including Malaysia is the devastating disease known as white root disease (WRD) caused by *Rigidoporus microporus*. This disease has been causing considerable latex yield loss and collapse of the mature rubber trees, consequently affecting its contribution to the economy of rubber producing countries. Thus, the search on using biological control agents (BCAs) against *R. microporus* in rubber tree has been focused in this study with locally isolated fungal species from the rhizosphere of healthy trees (HEA) and white root rot diseased trees (DIS). There were five different isolates of white root rot pathogen cultures, namely RL20, RL21, RL22, RL25 and RL26 were obtained from the Laboratory of Crop Improvement and Protection Unit, Rubber Research Institute of Malaysia (RRIM). All the pathogen isolates were subjected to morphological and molecular characterization for the species confirmation as *R. microporus*. Virulence among the pathogen isolates was determined in the pathogenicity test. Next, the soil samples collected from the rhizosphere of HEA and DIS were underwent serial dilution of 10^2 to 10^4 as to isolate the potential BCAs. The fungal isolation was performed on the potato dextrose agar Petri plates with species confirmation work was done by morphological and molecular identification. There were 35 fungal isolates that have been identified from both of the soils and their ability to inhibit the growth of *R. microporus* was screened in dual culture assay. Among these, there were four isolates from the genus of *Trichoderma*, i.e *T. asperellum* ST011, *T. spirale* HT009, *T. koningiopsis* HT001 and *T. reesei* ST013 have demonstrated greatest inhibition effect on the radial growth of *R. microporus* with majority achieved of $> 75\%$. The ability of the *Trichoderma* isolates to serve as BCAs against *R. microporus* were further determined through the aspects of mycoparasitism, antibiosis, enzymatic and competition activities. The mycoparasitic activity of *Trichoderma* isolates has been revealed in the scanning electron microscopy (SEM). While antibiosis activities of *Trichoderma* isolates against *R. microporus* were tested in double plate and culture filtrate assays for their volatile and non-volatile effects. The natural compounds

present in the secondary metabolites were further identified using the gas chromatography mass spectrometry (GC-MS) test, with some of the compounds were reported to have antimicrobial functions. The selected *Trichoderma* isolates have also revealed promising results on the production of chitinase, cellulase and glucanase enzymes in their respective qualitative and quantitative assays. Besides, they also possessed some plant growth-promoting activities to various degrees. Later, a scoring of antagonistic activity was done to select the best two performed fungal isolates in the biocontrol mechanisms as to test for their effectiveness against *R. microsporus* in the nursery trial. The nursery trial was conducted through the preparation of biocontrol suspension in the concentration of 10^8 cfu/mL as to suppress the disease incidence caused by *R. microsporus*. The percentage of efficacy was calculated based on the disease severity index of above and below grounds symptoms on each of the treatments. The present study demonstrated that the antagonists were able to boost in the soil and further compete with *R. microsporus* whereby the single application of *T. asperellum* and the combination of both *Trichoderma* isolates were more promising. The disease suppression by BCAs were observed to have similar extend as of the chemical treatment which suggests that the selected *Trichoderma* isolates especially *T. asperellum* was a potential candidate for the biocontrol of *R. microsporus* with its good persistence in the soil.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PENCIRIAN DAN POTENSI AGEN KAWALAN BIOLOGI TERHADAP
PATOGEN JAMUR AKAR PUTIH (*Rigidoporus microporus*) PADA POKOK
GETAH (*Hevea brasiliensis* Müll. Arg.)**

Oleh

GO WEN ZE

Disember 2019

Pengerusi: H'ng Paik San, PhD
Fakulti: Perhutanan

Getah merupakan komoditi kedua terpenting di Malaysia yang ditanam untuk penghasilan susu getah. Malangnya, isu utama yang dihadapi oleh majoriti negara-negara pengeluar getah, termasuk Malaysia adalah penyakit ganas menular yang dikenali sebagai penyakit jamur akar putih (JAP) yang disebabkan oleh *Rigidoporus microporus*. Penyakit ini telah menyebabkan kehilangan hasil lateks yang banyak dan kemusnahan pada pokok getah yang matang, seterusnya menjejaskan sumbangannya kepada ekonomi negara pengeluar getah. Justerunya, pencarian menggunakan agen kawalan biologi (BCAs) terhadap *R. microporus* dalam pokok getah telah difokuskan dalam kajian ini dengan isolasi tempatan bagi spesies kulat dari rizosfera pokok sihat and pokok yang mempunyai penyakit JAP. Terdapat lima isolat patogen JAP, iaitu RL20, RL21, RL22, RL25 dan RL26 yang diperolehi terus dari Unit Peningkatan Tanaman dan Perlindungan Tanaman, Lembaga Getah Malaysia (LGM). Semua isolat patogen tertakluk kepada pencirian morfologi dan molekul untuk pengesahan spesies sebagai *R. microporus*. Virulensi di antara isolat pathogen kemudiannya ditentukan dalam ujian patogenik. Sampel tanah yang dikumpulkan dari rizosfera pokok getah yang sihat dan pokok yang mempunyai penyakit JAP telah menjalani pencairan bersiri 10^2 hingga 10^4 untuk mengasingkan BCAs yang berpotensi. Pengasingan kulat dilakukan pada agar dextrose kentang di dalam plat Petri dengan kerja pengesahan species dilakukan melalui identifikasi morfologi dan molekul. Terdapat 35 isolat kulat yang telah dikenalpasti dari kedua-dua jenis tanah dan keupayaan isolat kulat dalam perencatan pertumbuhan *R. microporus* telah ditunjukkan dalam ujian dua kultur secara *in vitro*. Antaranya, terdapat empat isolat dari genus *Trichoderma*, iaitu *T. asperellum* ST011, *T. spirale* HT009, *T. koningiopsis* HT001 dan *T. reesei* ST013 telah menunjukkan kesan perencatan tertinggi pada pertumbuhan radius *R. microporus* dengan majoriti mencapai > 75%. Keupayaan isolat *Trichoderma* untuk berfungsi sebagai BCAs terhadap *R. microporus* telah ditentukan dengan lebih lanjut melalui kajian mycoparasitisme, antibiosis, enzimatik dan persaingan. Kegiatan mycoparasitik isolat *Trichoderma* telah ditunjukkan dalam pengimbasan mikroskop elektron (SEM).

Manakala aktiviti antibiosis oleh isolat *Trichoderma* terhadap *R. microporus* telah diuji dalam plat dua dan ujian turasan kultur untuk kesan volatil dan bukan volatil. Sebatian-sebatian semulajadi yang terdapat di dalam metabolit sekunder dikenalpasti dengan menggunakan ujian spektrometri massa kromatografi gas (GC-MS), dengan beberapa sebatian dilaporkan mempunyai fungsi antimikrobial. Isolat *Trichoderma* yang dipilih juga telah menunjukkan kesan yang menjanjikan dengan pengeluaran enzim kitinase, selulase dan glukonase dalam ujian kualitatif dan kuantitatif masing-masing. Selain itu, mereka juga menunjukkan keupayaan mempromosikan pertumbuhan pada pokok dalam pelbagai darjah. Kemudian, pemarkahan aktiviti antagonistik dilakukan untuk memilih dua isolate yang terbaik dalam mekanisme kawalan biologi untuk menguji keberkesananannya terhadap *R. microporus* dalam percubaan tapak semaian. Percubaan tapak semaian telah dijalankan melalui penyediaan suspensi kawalan biologi dalam konsentrasi 10^8 cfu/mL untuk mengurangkan kejadian penyakit JAP yang disebabkan oleh *R. microporus*. Peratusan keberkesananannya dikira berdasarkan indeks keparahan penyakit daripada simptom di atas dan di bawah tanah pada setiap rawatan. Kajian ini membuktikan bahawa antagonis mampu merangsang di dalam tanah dan seterusnya bersaing dengan *R. microporus* dimana aplikasi tunggal *T. asperellum* dan gabungan kedua-dua isolat *Trichoderma* yang lebih menjanjikan. Pengurangan gejala penyakit oleh kawalan biologi diperhatikan mempunyai persamaan seperti di dalam rawatan kimia yang seterusnya mencadangkan bahawa isolat *Trichoderma* yang dipilih terutamanya *T. asperellum* adalah calon yang berpotensi untuk kawalan biologi terhadap *R. microporus* dengan ketahananannya yang baik di dalam tanah.

ACKNOWLEDGEMENT

I would like to gratefully acknowledge various people who have been journey with me in recent years as I have worked on my postgraduate study. First and foremost, my deep gratitude goes to my family members, especially my parents Mr. Go Heng Her and Mdm. Ng Swee Chai and siblings for the encouragement and support given during my difficult times.

I owe an enormous debt of gratitude to my supervisor Assoc. Prof. Dr. H'ng Paik San for providing me necessary technical suggestions, guidance and support during my research pursuit. His wise counsel has made my PhD accomplishment a possible and going smoothly. I would also like to convey my great appreciation to Prof. Dr. Wong Mui Yun for providing expert recommendation, good instruction and deep encouragement. I have to thanks Prof. Dr. Luqman Chuah, Assoc. Prof. Dr. Tan Geok Hun and Dr. Salmiah Ujang for serving as my supervisory committee members, expertly guided me throughout my research study and thesis writing.

My appreciation also extends to my seniors, Dr. Chin Kit Ling, Dr. Lee Seng Hua, Dr. Lum Wei Chen, Dr. Kwan Yee Min, Dr. Chai Ee Wen, Dr. Wong Lih Juin for helping me enormously, especially with their guidance on research study and thesis writing. Besides, I would like to thank my juniors, Dr. Lee Chuan Li, Khoo Pui San, Bernice Andrew and Kong Wai Jern who has helped me in certain parts of my research. Not forgetting my coursemates, Dr. Wong Wan Zhen and Beatrice Hon Jia Qi for their understanding and encouragement given during my tough time.

I am also very grateful to Encik Zarawi, Encik Aizat and Encik Soni for their kind assistance in getting the source of samples and information regarding the rubber disease. And Rubber Research Institute of Malaysia (RRIM), Sungai Buloh for providing an excellent study site during my research. My special thanks are also extended to Dr. Sabiha and Dr. Razak for giving the flexibility to use their laboratory facilities. My research works would not have been smooth and easy without the facilities provided. Not forgetting the laboratory staffs of Faculty of Forestry, Cik Fatimah, Encik Lokman, Puan Maizatul, Encik Zamani and Encik Alagan for their kind assistance throughout this study.

I would also like to acknowledge a group of people from Yuan Rong Buddhist Society, for their personal generosity and support during my postgraduate study. Special thanks to Mr. Tong Jin Kock for his timely suggestions and constant encouragement and Mr. Wong Wai Fong for his manpower support on nursery works. I am extremely thankful to Dr. Evan Chin Hui See and Mr. You Kian Giap for their timely advice on scholarly and scientific approach which have help me to a very great extend to accomplish my PhD.

My utmost gratitude to the Ministry of Higher Education Malaysia for the MyBrain scholarship funding which has made my life easier with stable financial support during the first three years of my study.

Last but not least, I would like to thank Buddha for giving me the strength to make my PhD life a successful and a colourful indeed.



I certify that a Thesis Examination Committee has met on 06 December 2019 to conduct the final examination of Go Wen Ze on her thesis entitled "Characterization and Potential Biological Control Agent against White Root Rot Pathogen (*Rigidoporus microporus*) in Rubber Tree (*Hevea brasiliensis* Müll.Arg.)" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Manohar a/l Mariapan, PhD

Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Chairman)

Wan Zuhainis binti Saad, PhD

Associate Professor
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Internal Examiner)

Ganesan a/l Vadamalai, PhD

Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Internal Examiner)

Wang Zonghua, PhD

Professor
Fujian Agriculture and Forestry University
China
(External Examiner)

ZURIATI AHMAD ZUKARNAIN, PhD

Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 03 March 2020

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

H'ng Paik San, PhD

Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Chairman)

Luqman Chuah Abdullah, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Wong Mui Yun, PhD

Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Tan Geok Hun, PhD

Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Salmiah Ujang, PhD

Department of Forest Production
Forest Research Institute Malaysia
Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 12 March 2020

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, reports, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in theUniversiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: _____

Name and Matric No.: _____

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____

Name of Chairman

of Supervisory

Committee: Assoc. Prof. Dr. H'ng Paik San

Signature: _____

Name of Member

of Supervisory

Committee: Prof. Dr. Luqman Chuah Abdullah

Signature: _____

Name of Member

of Supervisory

Committee: Prof. Dr. Wong Mui Yun

Signature: _____

Name of Member

of Supervisory

Committee: Assoc. Prof. Dr. Tan Geok Hun

Signature: _____

Name of Member

of Supervisory

Committee: Dr. Salmiah Ujang

TABLE OF CONTENTS

	Page
ABSTRACT	i
ABSTRAK	iii
ACKNOWLEDGEMENTS	v
APPROVAL	vii
DECLARATION	ix
LIST OF TABLES	xv
LIST OF FIGURES	xvii
LIST OF ABBREVIATIONS	xxii
CHAPTER	
1	
INTRODUCTION	1
1.1 Background	1
1.2 Problem Statements	2
1.3 Justification	2
1.4 Objectives of the Study	3
2	
LITERATURE REVIEW	4
2.1 Rubber Tree [<i>Hevea brasiliensis</i> (Wild. ex Adr. de Juss) Müll. Arg.]	4
2.2 Rubber Tree Diseases	7
2.3 White Root Rot of Rubber Tree	9
2.3.1 The Pathogen <i>R. microporus</i>	9
2.3.2 Disease Symptoms and Epidemiology	9
2.3.3 Disease Management	11
2.4 Soil Microorganisms and the Rhizosphere Microbiome	13
2.5 Biological Control of Plant Diseases	14
2.6 Mechanisms of Action of BCAs	19
3	
PATHOGENICITY AND CHARACTERIZATION OF WHITE ROOT ROT PATHOGEN (<i>Rigidoporus microporus</i>) IN RUBBER TREE (<i>Hevea brasiliensis</i>)	23
3.1 Introduction	23
3.2 Materials and Methods	24
3.2.1 Source of White Root Rot Pathogen	24
3.2.2 Morphological Characterization of White Root Rot Pathogen	24
3.2.3 Molecular Identification of White Root Rot Pathogen	25
3.2.4 Phylogenetic Tree Analysis	26
3.2.5 Pathogenicity Test	28

3.2.6	Cultural Characterization of <i>R. microporus</i> isolate RL21	29
3.2.7	Experimental Design and Statistical Analysis	30
3.3	Results and Discussion	31
3.3.1	Morphological Characterization of White Root Rot Pathogen	31
3.3.2	Molecular Identification of White Root Rot Pathogen	34
3.3.3	Phylogenetic Analysis	36
3.3.4	Pathogenicity Test	38
3.3.5	Cultural Characterization	42
3.4	Conclusion	47
4	BIOCONTROL POTENTIAL OF MYCOFLORA ISOLATED FROM SOIL AROUND HEALTHY AND SYMPTOMATIC RUBBER TREES	48
4.1	Introduction	48
4.2	Materials and Methods	49
4.2.1	Study Site	49
4.2.2	Soil Sample Collection	51
4.2.3	Isolation of Soil Mycoflora	52
4.2.4	Morphological Characterization of Soil Mycoflora	53
4.2.5	Molecular Identification	53
4.2.6	Antagonism Test	53
4.2.7	Experimental Design and Statistical Analysis	54
4.3	Results and Discussion	55
4.3.1	Morphological Characterization of Soil Mycoflora	55
4.3.2	Molecular Identification of Soil Mycoflora	63
4.3.3	Occurrence and Distribution of Soil Mycoflora Isolated from the Rhizosphere of HEA and DIS Trees in RRIM, Sg. Buloh	71
4.3.4	Antagonism Test	75
4.4	Conclusion	81

5	IN VITRO ANTAGONISTIC ACTIVITIES OF ISOLATED <i>Trichoderma</i> spp. AGAINST <i>Rigidoporus microporus</i>	82
	5.1 Introduction	82
	5.2 Materials and Methods	83
	5.2.1 The Study of Antagonist-pathogen Interaction through Scanning Electron Microscopy (SEM)	83
	5.2.2 Antibiosis Activities	84
	5.2.3 Analysis of Antifungal Metabolites by GC-MS	85
	5.2.4 Production of Hydrolytic Enzymes	86
	5.2.5 Growth Promotion Activities	88
	5.2.6 Effects of Cultural Parameters on Mycelial Growth of <i>Trichoderma</i> Isolates	89
	5.2.7 Statistical Analysis	89
	5.3 Results and Discussion	89
	5.3.1 Microscopy Study of the Antagonist-pathogen Interaction	89
	5.3.2 Production of Volatile and Non-volatile Compounds	91
	5.3.3 Identification of Antifungal Metabolites by GC-MS Method	96
	5.3.4 Production of Hydrolytic Enzymes through Qualitative and Quantitative Assays	102
	5.3.5 Growth Promotion Activities	109
	5.3.6 Cultural Characterization	116
	5.4 Conclusion	121
6	EFFICACY OF <i>Trichoderma asperellum</i> AND <i>Trichoderma spirale</i> ON WHITE ROOT ROT DISEASE IN NURSERY-GROWN RUBBER SEEDLINGS	122
	6.1 Introduction	122
	6.2 Materials and Methods	123
	6.2.1 Rubber Tree Preparation	123
	6.2.2 Preparation of <i>R. microporus</i> Inoculum	123
	6.2.3 Preparation of Biocontrol Suspension	124
	6.2.4 Persistence of Selected <i>Trichoderma</i> Suspensions in Soil	124
	6.2.5 Inoculation of Rubber Seedlings with <i>R. microporus</i>	125

	6.2.6	Nursery Assessment	127
	6.2.7	Statistical Analysis	128
6.3		Results and Discussion	128
	6.3.1	Persistence of the Selected <i>Trichoderma</i> Suspensions	128
	6.3.2	The Effect on Plant Growth	131
	6.3.3	The Effect on <i>R. microporus</i> Mycelium Mass	133
	6.3.4	Disease Assessment	134
	6.3.5	Histology of Penetration and Infection of <i>R. microporus</i> through Transmission Electron Microscopy (TEM) Observation	139
	6.4	Conclusion	141
7		SUMMARY, CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH	142
	7.1	Summary	142
	7.2	Conclusion	143
	7.3	Recommendations	143
		REFERENCES	145
		APPENDICES	175
		BIODATA OF STUDENT	210
		LIST OF PUBLICATIONS	211

LIST OF TABLES

Table		Page
2.1	Rubber tree diseases and causal agents	8
2.2	Fungi developed or being developed for the biological control of disease (Butt and Copping, 2000; Burges, 1998)	17
2.3	Perceived advantages and disadvantages of the commercial development of biological disease control agents relative to existing chemical control measures (Butt <i>et al.</i> , 2001)	19
3.1	Source of white root rot pathogen obtained from the Laboratory of Crop Improvement and Protection Unit, RRIM	24
3.2	The eight most homologous microorganisms and one outgroup selected from NCBI GenBank in comparison to the white root rot pathogen isolates	27
3.3	Results of BLAST search and the accession number of white root rot pathogen isolates deposited in GenBank	35
3.4	Disease severity index of rubber seedling clone RRIM600 based on above and below ground symptoms six months after challenged with five different isolates of <i>R. microporus</i>	41
3.5	Mortality rate of rubber seedling clone RRIM600 inoculated with five different isolates of <i>R. microporus</i>	41
4.1	Physico-chemical properties of the soil collected from <i>Hevea</i> germplasm, Field 23, Sg. Buloh	49
4.2	Coordinate of each soil sampling for HEA and DIS at <i>Hevea</i> germplasm, Field 23, Sg. Buloh	52
4.3	Fungal macroscopic morphological identification	56
4.4	Fungal microscopic morphological identification	60
4.5	Fungal species identified with relationship to the genus or species and its identity percentage from NCBI website	67

4.6	Antifungal activity of fungal isolates against <i>R. microporus</i> in five-day-old dual culture assays	77
5.1	Mean radial growth and PIRG values of <i>Trichoderma</i> isolates against <i>R. microporus</i> at 5 DAI in double plate assay	92
5.2	Mean radial growth and PIRG values of <i>Trichoderma</i> isolates against <i>R. microporus</i> at 5 DAI of culture filtrate assay	95
5.3	Compounds identified in the methanol extracts of <i>Trichoderma</i> isolates by GC-MS, each having a > 1% peak area and a \geq 50% match quality at NIST-17 library search	99
5.4	Quantitative of chitinase, β -1, 3-glucanase and cellulase enzymes production by <i>Trichoderma</i> isolates	105
5.5	Production of IAA by <i>Trichoderma</i> isolates	111
5.6	Scoring of antagonistic activity by <i>Trichoderma</i> isolates <i>in vitro</i>	115
6.1	Treatments of <i>Trichoderma</i> suspensions and chemical fungicide on rubber seedlings for disease assessment in nursery	126
6.2	Environmental conditions at nursery of Faculty of Forestry, UPM in the period of January to June 2019	126
6.3	Viability of <i>Trichoderma</i> suspensions in the soil up to six months	130
6.4	Effect of different treatments on the plant height and diameter increments of the rubber seedlings after six months of post- inoculation	132
6.5	Effect of different treatment on the severity of disease symptoms caused by <i>R. microporus</i> in rubber seedlings clone RRIM600 six months after post-inoculation	137
6.6	Mortality rate of rubber seedling clone RRIM600 in different treatments after being challenged with <i>R. microporus</i>	138

LIST OF FIGURES

Figure		Page
2.1	<i>Hevea brasiliensis</i> or Para rubber: (a) shoot with dehiscing fruit, (b) inflorescence, (c) male flower cut open, (d) female flower in longitudinal section, [e(i)-e(ii)] fruit and (f) seed (Source: Purseglove, 1977)	5
2.2	Species distribution of <i>H. brasiliensis</i> (Source: Orwa <i>et al.</i> , 2009)	6
2.3	Formation of white rhizomorphs on the root surface of rubber tree	10
2.4	Formation of <i>R. microporus</i> fruiting body at the collar of dead stump	10
2.5	Mode of action of <i>Trichoderma</i> spp. against pathogen and plant growth improvement (Source: Waghunde <i>et al.</i> , 2016)	20
3.1	Diameter measurement of fungal colony	29
3.2	Characteristic of white root rot pathogen: (a) colony on PDA at 8 DAI, (b) hypha, (c) generative hypha (arrow) and (d) basidiospores. (Scale bar =10 μ m; magnification: x40)	32
3.3	Macroscopic and microscopic characteristics of white root rot pathogen isolates obtained from the Laboratory of Crop Improvement and Protection Unit, RRIM Sg. Buloh. Macroscopic view of white root rot pathogen isolates: (a) RL20, (b) RL21, (c) RL22, (d) RL25 and (e) RL26; microscopic view of white root rot pathogen isolates: (f) RL20, (g) RL21, (h) RL22, (i) RL25 and (j) RL26. (Scale bar =10 μ m; magnification: x40)	33
3.4	PCR amplification of five isolates of white root rot pathogen using universal primers, ITS1 and ITS4. The band sizes were between 500 to 750 bp	35

3.5	Evolutionary relationships based on the ITS region of the genomic rRNA gene of eight <i>Rigidoporus</i> isolates and one outgroup search derived from maximum likelihood analysis, showing the relationship between the five <i>R. microporus</i> isolates obtained from laboratory of RRIM with other closely related isolates and species. The numbers shown over selected branches denote the percentage of bootstrap values after 1000 replications	37
3.6	Sign and symptoms caused by <i>R. microporus</i> on rubber seedling: (a) full coverage of white rhizomorphs on the root surface first MAI, (b) formation of white rhizomorphs on the collar region first MAI (arrow), (c) penetration of rhizomorphs to the root system causing root rotted third MAI, (d) healthy root from control seedling during third month observation, (e) foliar symptom on rubber tree after white root rot infection third MAI and (f) healthy rubber tree with green leaves from control seedling during third month observation	39
3.7	Re-isolation of <i>R. microporus</i> for disease confirmation: (a) infected root plugs plated on MEA medium fifth day after surface sterilization and (b) seven-day-old subculture of <i>R. microporus</i> from previous re-isolation plate	40
3.8	Mycelial growth of <i>R. microporus</i> on different culture media at 7 DAI: (a) MEA medium and (b) PDA medium	43
3.9	Effects of culture media on the growth of <i>R. microporus</i> within 6 days. n=5	43
3.10	Effects of different pH levels on the mycelial growth of <i>R. microporus</i> at 3 DAI. n=5	44
3.11	Effects of different incubation temperature on the mycelial growth of <i>R. microporus</i> at 3 DAI. n=5	45
3.12	The growth of <i>R. microporus</i> was inhibited at the temperature of 40°C on MEA plate taken at 6 DAI	46
3.13	Effects of different photoperiods on the mycelial growth of <i>R. microporus</i> at 3 DAI. n=5	47
4.1	Map of study site at RRIM, Sg. Buloh	50

4.2	Rubber tree health conditions at study site: (a) healthy tree and (b) white root rot diseased tree at <i>Hevea</i> germplasm, Field 23, Sg. Buloh	50
4.3	Location of sampling points for HEA and DIS in <i>Hevea</i> germplasm, Field 23, Sg. Buloh	51
4.4	Dual culture assay plate	54
4.5	Macroscopic characteristic of culturable fungal species on PDA medium isolated from the rhizosphere of HEA and DIS trees	59
4.6	Microscopic characteristic of culturable fungal species isolated from the rhizosphere of HEA and DIS trees based on the structure of conidia, conidiophores and arrangement of spores (Scale bar=10 μ m; magnification: x40)	62
4.7	Agarose gel electrophoresis: PCR amplification of soil mycoflora isolated from the rhizosphere of HEA tree under UV transilluminator. Bands of DNA amplicon were between 500-750bp	64
4.8	Agarose gel electrophoresis: PCR amplification of soil mycoflora isolated from the rhizosphere of DIS soil under UV transilluminator. Bands of DNA amplicon were between 500-750bp, except for sample isolate ST009 (below 500bp)	65
4.9	Percentage of contribution of each genus in the rhizosphere of HEA and DIS trees based on culture-dependant method	72
4.10	Interaction assay between <i>R. microporus</i> (left) and 35 isolated soil mycoflora (right) at 5 DAI on PDA plate: (1) <i>T. koningiopsis</i> , (2) <i>Talaromyces</i> sp., (3) <i>P. lilacinum</i> , (4) <i>F. oxysporum</i> , (5) <i>T. aculeatum</i> , (6) <i>T. aculeatum</i> , (7) <i>C. bainieri</i> , (8) <i>M. anisopliae</i> , (9) <i>T. spirale</i> , (10) <i>Penicillium</i> sp., (11) <i>P. lilacinum</i> , (12) <i>Penicillium</i> sp., (13) <i>Clonostachys</i> sp., (14) <i>S. boydii</i> , (15) <i>T. koningiopsis</i> , (16) <i>A. nomius</i> , (17) <i>Penicillium</i> sp., (18) <i>B. spectabilis</i> , (19) <i>G. butleri</i> , (20) <i>Penicillium</i> sp., (21) <i>T. spirale</i> , (22) <i>F. oxysporum</i> , (23) <i>T. spirale</i> , (24) <i>X. leucotricha</i> , (25) <i>Penicillium</i> sp., (26) <i>Trichosporiella</i> sp., (27) <i>L. theobromae</i> , (28) <i>T. asperellum</i> , (29) <i>A. cupreus</i> , (30) <i>T. reesei</i> , (31) <i>T. koningiopsis</i> , (32) <i>W. laurinus</i> , (33) <i>P. singorense</i> , (34) <i>B. spectabilis</i> , (35) <i>Clonostachys</i> sp., and (36) control plate	76

5.1	Test of volatile substances emitted by <i>Trichoderma</i> isolates on the mycelial growth of <i>R. microporus</i> through inverted plate technique	84
5.2	Interaction of <i>Trichoderma</i> isolates and <i>R. microporus</i> : (a) <i>T. koningiopsis</i> HT001 Vs. <i>R. microporus</i> , (b) <i>T. spirale</i> HT009 Vs. <i>R. microporus</i> , (c) <i>T. asperellum</i> ST011 Vs. <i>R. microporus</i> , (d) <i>T. reesei</i> ST013 Vs. <i>R. microporus</i> with appressorium-like structure (yellow arrow) and (e) normal appearance of <i>R. microporus</i> hyphae. The coiling action of <i>Trichoderma</i> isolates hyphae (h) on <i>R. microporus</i> hyphae (r). (Scale bar: a-e=10 µm; magnification: x1000)	90
5.3	Double plate assay by <i>Trichoderma</i> isolates against <i>R. microporus</i> at 5 DAI on PDA medium: (a) <i>T. koningiopsis</i> HT001, (b) <i>T. spirale</i> HT009, (c) <i>T. asperellum</i> ST011, (d) <i>T. reesei</i> ST013 and (e) control plate	92
5.4	<i>R. microporus</i> on culture filtrate of <i>Trichoderma</i> isolates (<i>T. koningiopsis</i> HT001, <i>T. spirale</i> HT009, <i>T. asperellum</i> ST011 and <i>T. reesei</i> ST013) on PDA medium at (a) 75%, (b) 50%, (c) 25% concentration and (d) control plate at 5 DAI	94
5.5	GC-MS chromatogram of the methanolic extract of <i>Trichoderma</i> isolates: (a) <i>T. koningiopsis</i> HT001, (b) <i>T. spirale</i> HT009, (c) <i>T. asperellum</i> ST011 and (d) <i>T. reesei</i> ST013	98
5.6	Production of chitinase enzyme by <i>Trichoderma</i> isolates on agar plate amended with colloidal chitin: (a) <i>T. koningiopsis</i> HT001, (b) <i>T. spirale</i> HT009, (c) <i>T. asperellum</i> ST011, (d) <i>T. reesei</i> ST013 and (e) control plate	104
5.7	Production of cellulase enzyme by <i>Trichoderma</i> isolates on CMC agar plate: (a) <i>T. koningiopsis</i> HT001, (b) <i>T. spirale</i> HT009, (c) <i>T. asperellum</i> ST011, (d) <i>T. reesei</i> ST013 and (e) control plate	107
5.8	Phosphate solubilization performed by <i>Trichoderma</i> isolates on PVK medium: (a) <i>T. koningiopsis</i> HT001, (b) <i>T. spirale</i> HT009, (c) <i>T. asperellum</i> ST011, (d) <i>T. reesei</i> ST013 and (e) control plate	110

5.9	Production of siderophores by <i>Trichoderma</i> isolates on CAS agar plates: (a) <i>T. koningiopsis</i> HT001, (b) <i>T. spirale</i> HT009, (c) <i>T. asperellum</i> ST011, (d) <i>T. reesei</i> ST013 and (e) control plate	112
5.10	Effects of different pH levels on the mycelial growth of <i>Trichoderma</i> isolates at 2 DAI. n=4	117
5.11	Effects of different incubation temperature on the mycelial growth of <i>Trichoderma</i> isolates at 2 DAI. n=4	118
5.12	Effects of different photoperiods on the mycelial growth of <i>Trichoderma</i> isolates at 2 DAI. n=4	119
6.1	Four-month-old RRIM600 rubber seedlings cultivation in nursery of Faculty of Forestry, UPM	123
6.2	Preparation of <i>R. microporus</i> inoculum: (a) fresh rubber wood block cut into the dimension of 6 x 6 x 6 cm and (b) <i>R. microporus</i> inoculum after one month of incubation	124
6.3	Effect of different treatments on the amount of mycelium collected from soil and lateral root of the rubber seedlings throughout six months of post-inoculation	134
6.4	Disease symptoms of above ground caused by <i>R. microporus</i> infection in different treatments after six months of post-inoculation: (a) T1, (b) T2, (c) T3, (d) T4, (e) T5 and (f) T6	135
6.5	Disease symptoms of below ground caused by <i>R. microporus</i> infection in different treatments after six months of post-inoculation: (a) T1, (b) T2, (c) T3, (d) T4, (e) T5 and (f) T6	135
6.6	TEM observations of root section in rubber seedlings clone RRIM600 six months after post-inoculation: (a) healthy plant in T1, (b) plant inoculated with <i>R. microporus</i> in T2, (c) <i>R. microporus</i> inoculated plant pretreated with <i>T. asperellum</i> in T3, (d) <i>R. microporus</i> inoculated plant pretreated with <i>T. spirale</i> in T4, (e) <i>R. microporus</i> inoculated plant pretreated with combination of both <i>Trichoderma</i> in T5 and (f) <i>R. microporus</i> inoculated plant treated with chemical propiconazole in T6. CW: cell wall; CH: chloroplast; M: mitochondrion and h: hyphae of <i>R. microporus</i> (arrow). (Scale bar= 2 µm; magnification: x2500)	140

LIST OF ABBREVIATIONS

ANOVA	analysis of variance
BCAs	biocontrol agents
BLAST	Basic Local Alignment Search Tool
bp	base pair
CAS	chrome azurol S
cfu	colony forming unit
CMC	carboxymethyl cellulose
CRD	Completely Randomized Design
CWDEs	cell wall degrading enzymes
DAI	days after inoculation
ddH ₂ O	double distilled water
dH ₂ O	distilled water
DIS	white root rot diseased trees
DSI	disease severity index
DNA	deoxyribonucleic acid
DNS	3,5-dinitrosalicylic acid
EDTA	ethylenediaminetetraacetic acid
GC-MS	gas chromatography-mass spectrometry
HDTMA	hexa decyl tri methyl-ammonium bromide
HEA	healthy trees
HPLC	High Performance Liquid Chromatography
HPP	high performance plastics
IAA	indole acetic acid
IBS	Institute Bioscience
IDM	integrated disease management
IRRDB	International Rubber Research and Development Board
ITS	internal transcribed spacer
MAI	months after inoculation
MEA	malt extract agar
MEGA	Molecular Evolutionary Genetics Analysis
NCBI	National Center for Biotechnology Information
NIST	National Institute of Standards and Technology
PCR	Polymerase Chain Reaction
PDA	potato dextrose agar
PDB	potato dextrose broth
PIRG	percentage inhibition of radial growth
POC	percentage of contribution
PVK	Pikovskaya
RCBD	Randomized Complete Block Design
rpm	Revolutions per minute
RRIM	Rubber Research Institute of Malaysia
SD	standard deviation
SEM	scanning electron microscopy
SPSS	Statistical Package for the Social Sciences
TAE	Tris-acetate EDTA
TEM	transmission electron microscopy

TLE
Tris-HCl
UPM
WRD

Trichoderma Liquid Enzyme
Tris hydrochloride
Universiti Putra Malaysia
white root disease



CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia was once the largest producer of natural rubber in the world until late of 1980's (Ratnasingam *et al.*, 2012; Balsiger *et al.*, 2000). Nonetheless, Malaysia, together with Thailand and Indonesia still have account for 70% of rubber global supply, with Malaysia now a distant third behind the two neighbouring countries. Rubber is the second most important commodity in Malaysia after the "golden crop"- oil palm (Frost and Sullivan, 2009). This country is producing 165,000 tonnes (2.3%) of the world's total natural rubber and the industry has contributed 3.96% to national exports of the country (Natural Rubber Statistics, 2018). However, the white root disease (WRD) caused by *Rigidoporus microporus* is a looming threat to rubber growing areas in Malaysia.

The WRD also reported in Sri Lanka, Thailand, India, Indonesia, West and Central Africa as it causes a serious loss of rubber yield in worldwide (Oghenekaro *et al.*, 2015; Omorusi, 2012; Jayasuriya and Thennakoon, 2007; Jayasinghe, 2001). According to Sail and Ahmad (2009), the white root rot disease of rubber is the most serious and it has caused a major problem for 43% of farmers in a smallholdings survey in Malaysia. It has brought a great loss to the rubber industry as it affected the latex yield and infected the young rubber tree as early at 5 years old (Semangun, 2000). The mean annual WRD incidence is reported to fall between 5 and 15% in rubber plantations surveyed in Malaysia (Soepena, 1993). Over a period of time, half of the rubber trees in a plantation are nearly lost to the disease. The natural resistance exhibits in the rubber tree itself has often breaks down due to the colonisation of living tissues by the pathogens to obtain the nutrients. It damaged and weakens the host plant with toxins or by impeding the plants defence mechanism (Jayasuriya, 2004).

The economics of WRD has been discussed as early in 1977 by Liyanage and partners. The losses resulting from the disease infection during the early stages of planting have brought upon extra expenditure owing to the need of resupplying the young rubber trees. In mature plantings, the losses have faded the latex production due to the reduction in trees per hectare (Jayaratne *et al.*, 2001). Apart from yield loss due to tree death, the cost of treating the root disease and replacing the infected young tree has contributed to a higher cost of production in the rubber planting.

1.2 Problem Statements

To date, not many extensive works have been done in Malaysia regarding the biology, epidemiology and pathogenicity of the WRD caused by *R. microporus* in rubber. There is a lack of information regarding the isolates or strains of the white root rot pathogen present in Malaysia and their genetic variation is yet to be studied. The isolation and identification of naturally occurring mycoflora from the soil of rubber plantation as potential BCAs in controlling *R. microporus* is also unrevealed. The search for isolates of microorganisms with antagonistic properties has often been done using solely laboratory method like culture plates that contained artificial medium. Furthermore, the use of these microorganisms as BCAs requires a comprehensive analysis of the biological principles on their mode of actions during the confrontation process with the targeted pathogen. More often, however, most of the researchers focused on the *in vitro* tests or artificial environments which are far from the situation in field which makes their research a limit (Knudsen *et al.*, 1997).

1.3 Justification

One must have a through knowledge of the pathogen, the host plant, and the environmental conditions that favour the infection when dealing with disease control measures. This is important as it could reduce the chances of wasting time and money which can lead to further plant losses. Hence, few isolates of white root rot pathogen need to be obtained from different location around Malaysia which provided by the laboratory of Rubber Research Institute of Malaysia, Sungai Buloh to determine their pathogenic variability and the characterization of the *R. microporus* associated to WRD using morphological and PCR analysis. This step is considered vital for a proper disease diagnosis and biological control management in later of the research.

Several studies from other countries have illustrated the potential of reducing WRD incidence using naturally occurring microorganisms (Ogbebor *et al.*, 2015; Ubogu, 2013; Kaewchai and Soyong, 2010; Jayasuriya and Thennakoon, 2007; Idwan *et al.*, 1992). In the ecological approach, the selected antagonists should be able to function in the same environmental condition as that of the pathogen they are to control (Knudsen *et al.*, 1997). Thus, the suitable places for the isolation of such ecologically adapted antagonists against the soil borne pathogen, *R. microporus* would be the rhizosphere of the host plant. In order to obtain the antagonists, soil samples were collected from the rhizosphere of healthy and white root rot diseased trees. Further screening was done against the pathogen, *R. microporus* after the morphological and molecular identification for each of the single species that being isolated.

On top of that, the successful use of the potential microorganisms for plant disease control would be enhanced by the understanding of biological control mechanisms in a more advance stage like biochemical tests. Therefore,

biochemical tests such as scanning electron microscopy (SEM) on mycoparasitism, enzymatic reaction, antibiosis activity and the screening of bioactive compounds were performed to elucidate the possible role of selected isolates as the potential antagonists against the white root rot pathogen.

The chemical treatment of the rubber trees is often ineffective once the visible symptoms of the WRD appeared (Mohd Farid *et al.*, 2009). As such, the application of biocontrol in this study was focused more on the preventive measure than curative measure. Before the artificial inoculation of the white root rot pathogen, the soils used for the nursery study were treated with the selected BCAs prepared in liquid suspension form. This study discussed the practicability of using alternative and economical method to control the WRD in young rubber seedlings using both the single and mix application of microorganism screened and identified from the study as the potential antagonists towards *R. microporus*.

1.4 Objectives of the Study

This research was therefore undertaken with the following specific objectives:

- i. To characterize the isolates of white root rot pathogen from different location in Malaysia and their pathogenicity test in rubber tree.
- ii. To identify potential fungal biocontrol agents from soil rhizosphere of healthy and white root rot diseased trees and their antagonistic properties against white root rot pathogen.
- iii. To determine the mode of actions involved in the biocontrol activity of selected fungal antagonists against the white root rot pathogen.
- iv. To determine the effectiveness of selected biocontrol agents against white root rot pathogen under nursery trial.

REFERENCES

- Agrawal, T., & Kotasthane, A.S. (2012). Chitinolytic assay of indigenous *Trichoderma* isolates collected from different geographical locations of Chhattisgarh in central India. *Springer Plus*, 2012(1): 73.
- Ahmad, F., Ahmad, I., & Khan, M.S. (2004). Indole acetic acid production by the indigenous isolates of *Azotobacter* and fluorescent *Pseudomonas* in the presence and absence of tryptophan. *Turkish Journal of Biology*, 29: 29–34.
- Ahmed, J.S., & Baker, R. (1987). Competitive saprophytic ability and cellulolytic activity of rhizosphere-competent mutants of *Trichoderma harzianum*. *Phytopathology*, 77: 358–362.
- Aislabie, J., & Deslippe, J.R. (2013). Soil Microbes and Their Contribution to Soil Services. In J.R. Dymond (Ed.), *Ecosystem Services in New Zealand – Conditions and Trends* (pp. 143–161). Lincoln: Manaaki Whenua Press.
- Akhter, K. (2005). Preservative treatment of rubberwood (*Hevea brasiliensis*) to increase its service life. The International Research Group in Wood Protection, Stockholm.
- Ali, H., & Nadarajah, K. (2014). Evaluating the efficacy of *Trichoderma* spp. and *Bacillus subtilis* as biocontrol agents against *Magnaporthe grisea* in rice. *Australian Journal of Crop Science*, 8(9): 1324–1335.
- Almeida, F.B., Cerqueira, F.M., Silva, R.N., Ulhoa, C.J., & Lima, A.L. (2007). Mycoparasitism studies of *Trichoderma harzianum* strains against *Rhizoctonia solani*: Evaluation of coiling and hydrolytic enzyme production. *Biotechnology Letters*, 29: 1189–1193.
- Alves, E., & Lucas, G.C. (2013). Scanning Electron Microscopy for Fungal Sample Examination Laboratory Protocols in Fungal Biology. In V.K. Gupta, M.G. Tuohy, M. Ayyachamy, K.M. Turner, A. O'Donovan (Eds.), *Laboratory Protocol in Fungal Biology: Current Methods in Fungal Biology* (pp. 133–150). New York (NY): Springer New York.
- Amaria, W., Harni, R., & Samsudin. (2015). Evaluation of antagonistic fungi in inhibiting the growth of *Rigidoporus microporus* causing white root disease in rubber plants. *Jurnal Tanaman Industri dan Penyegar*, 2(1): 51-60.
- Amelia, C.S., & Samson, R.A. (1972). The Genus *Talaromyces*: Studies on *Talaromyces* and Related Genera II. Studies in Mycology, No. 2, Centraalbureau voor Schimmelcultures, Baarn, Netherlands.

- Baetz, U. (2016). Root Exudates as Integral Part of Belowground Plant Defence. In C.M.F. Vos, K. Kazan (Eds.), *Belowground Defence Strategies in Plants, Signaling and Communication in Plants*. Cham, Switzerland: Springer.
- Bais, H.P., Weir, T.L., Perry, L.G., Gilroy, S., & Vivanco, J.M. (2006). The role of root exudates in rhizosphere interactions with plants and other organisms. *Annual Review of Plant Biology*, 57: 233–266.
- Balsiger, J., Bahdan, J., & Whiteman, A. (2000). *The Utilization, Processing and Demand for Rubberwood as a Source of Wood Supply*. APFC-Working Paper No. APFSOS/WP/50. FAO, Bangkok.
- Bano, N., & Musarrat, J. (2004). Characterization of a novel carbofuran degrading *Pseudomonas* sp. with collateral biocontrol and plant growth promoting potential. *FEMS Microbiology Letters*, 231: 13–17.
- Bara, M.T., Lima, A.L., & Ulhoa, C.J. (2003). Purification and characterization of an exo-beta-1,3-glucanase produced by *Trichoderma asperellum*. *FEMS Microbiology Letters*, 219: 81–85.
- Barakat, F.M., Abada, K.A., Abou-Zeid, N.M., & El-Gammal, Y.H.E. (2014). Effect of volatile and non-volatile compounds of *Trichoderma* spp. on *Botrytis fabae* the causative agent of faba bean chocolate spot. *American Journal of Life Sciences*, 2(6-2): 11–18.
- Barakat, H.M., Mahfoz, H.M., El-atroush, H., & Mohammed, M.A. (2010). Comparative study between the effects of the synthetic fungicide mancozeb and the biological fungicide plant guard on *Allium cepa* plant. *Egyptian Journal of Genetics and Cytology*, 39: 99–113.
- Barbosa, M.A., Rehn, G.K., Menezes, M., & Mariano, L.R. (2001). Antagonism of *Trichoderma* species on *Cladosporium herbarum* and their enzymatic characterization. *Brazil Journal of Microbiology*, 32: 98–104.
- Bartinicki-Garcia, S. (1973). Fundamental Aspects of Hyphal Morphogenesis. In J.M. Ashnorthand, J.E. Smith (Eds.), *Microbiology differentiation* (pp. 245-268). Cambridge, United Kingdom: University Press.
- Bell, D.K., Wells, D.H., & Markham, R.C. (1982). *In vitro* antagonism of *Trichoderma* species against six fungal plant pathogens. *Phytopathology*, 72: 379–382.
- Benhamou, N., & Chet, I. (1993). Hyphal interactions between *Trichoderma harzianum* and *Rhizoctonia solani*: Ultrastructure band gold cytochemistry of themycoparasitic process. *Phytopathology*, 83: 1062–1107.

- Benítez, T., Rincón, M.A., Limón, M.C., & Codón, C.A. (2004). Biocontrol mechanisms of *Trichoderma* strains. *International Microbiology*, 7(4): 249–260.
- Bernadette, M.E., Aoudou, Y., Aurélie, N.N., & Honoré, B.D. (2017). Antifungal activities of essential oils against *Rigidoporus lignosus*, causative agent of white root-rot disease of the rubber tree in Cameroon. *International Journal of Agriculture and Environmental Research*, 3(2): 1–10.
- Blakeman, J.P. (1978). Microbial competition for nutrients and germination of fungal spores. *Annals of Applied Biology*, 89: 151–155.
- Błaszczczyk, L., Siwulski, M., Sobieralski, K., Lisiecka, J., & Jędrzycka, M. (2014). *Trichoderma* spp. – Application and prospects for use in organic farming and industry. *Journal of Plant Protection Research*, 54(4): 309–317.
- Borges Chagas, L.F., Chagas Junior, A.F., Rodrigues de Carvalho, M., de Oliveira Miller, L. & Orozco Colonia, B.S. (2015). Evaluation of the phosphate solubilization potential of *Trichoderma* strains (Trichoplus JCO) and effects on rice biomass. *Journal of Soil Science and Plant Nutrition*, 15: 794–804.
- Boubekeur, S.B., Mahiout, D., Benzohra, I.E., & Benkada, M.Y. (2012). Antagonism of three *Trichoderma* species against *Botrytis fabae* and *B. cinerea*, the causal agents of Chocolate spot of faba bean (*Vicia faba* L.) in Algeria. *World Applied Sciences Journal*, 17(3): 278–283.
- Boughalleb-M' Hamdi, N., Salem, I.B., M'Hamdi, M. (2018). Evaluation of the efficiency of *Trichoderma*, *Penicillium* and *Aspergillus* species as biological control agents against four soil-borne fungi of melon and watermelon. *Egyptian Journal of Biological Pest Control*, 28: 25. Doi: [10.1186/s41938-017-0010-3](https://doi.org/10.1186/s41938-017-0010-3)
- Brady, N.C. (1990). *The Nature and Properties of Soils*. 10th Edn., New York: Macmillin Publishing Co.
- Briat, J.F., Fobis-Loisy, I., Grignon, N., Lobreaux, S., Pascal, N., Savino, G., Thoiron, S., Wiren, N., & Wuytswinkel, O. (1995). Cellular and molecular aspects of iron metabolism in plants. *Biocell*, 84: 69–81.
- Brimner, T.A., & Boland, G.J. (2003). A review of the non-target effects of fungi used to biologically control plant diseases. *Agriculture, Ecosystems and Environment*, 100: 3–16.
- Brotman, Y., Briff, E., Viterbo, A., & Chet, I. (2008). Role of swollenin, an expansin-like protein from *Trichoderma* in plant root colonization. *Plant Physiology*, 147: 779–789.

- Bruce, A. (1991). Control of growth of wood decay Basidiomycetes by *Trichoderma* spp. and other potentially antagonistic fungi. *Journal of Forest Products*, 41(2): 63–67.
- Bruce, A., & Highley, L.T. (1991). Control of growth of wood decay Basidiomycetes by *Trichoderma* spp. and other potentially antagonistic fungi. *Journal of Forest Products*, 41(2): 63–67.
- Burges, H.D. (1998). *Formulation of Microbial Pesticides*. Dordrecht: Kluwer Academic Publishers.
- Butt, T.M., & Copping, L. (2000). Fungal biological control agents. *Pesticide Outlook*, 11, 186–191.
- Butt, T.M., Harris, J.G., & Powell, K.A. (1999). Microbial Biopesticides: The European Scene. In R.H. Franklin, J.M. Julius (Eds.), *Methods in Biotechnology Vol. 5: Biopesticides Use and Delivery* (pp. 23–44). New Jersey: Humana Press Inc.
- Butt, T.M., Jackson, C. & Magan, N. (2001). Fungi as Biocontrol Agents. In M.W. John, D.L. Robert (Eds.), *Commercial Use of Fungi as Plant Disease Biological Control Agents: Status and Prospects* (pp. 9–22). United Kingdom: CABI publishing.
- Calistru, C., McLean, M., & Berjak, P. (1997). *In vitro* studies on the potential for biological control of *Aspergillus flavus* and *Fusarium moniliforme* by *Trichoderma* species 1. Macroscopical and microscopical observations of fungal interactions. *Mycopathologia*, 139: 115–121.
- Cesar, G-L., Francisco, V-A., Victor, G-P., Michelina, R., & Matteo, L. (2015). Changes in *Trichoderma asperellum* enzyme expression during parasitism of the cotton root rot pathogen *Phymatotrichopsis omnivore*. *Fungal Biology*, 119: 264–273.
- Chan, W.H., Tan, K.S., & Ong, T.S. (n. d.). Early Growth and Secondary Characteristics of RRIM 2000 Series Clones in a Large Plantation Group. (Unpublished article). Applied Agricultural Research Sdn. Bhd., Sungai Buloh.
- Chan, W.H., Wong, C.P., & Wong, C.C. (1991). Control of white root disease in immature rubber with three systematic fungicides. *The Planter*, 67: 251–265.
- Chandini, K.C., & Rajeshwari, N. (2017). Isolation and identification of soil fungi in Mattavara forest, Chikamagalur, Karnataka. *Journal of Pharmacognosy and Phytochemistry*, 6(5): 721–726.

- Chee, K.H. (1990). Recent development in rubber disease management. 3rd International Conference on Plant Protection in the Tropics. March 20-23, 1990, Pahang, Malaysia.
- Chérif, M., & Benhamou, N. (1990). Cytochemical aspects of chitin breakdown during the parasitic action of a *Trichoderma* sp. on *Fusarium oxysporium* sp. *radicis-licopersici*. *Phytopathology*, 80: 1406–1414.
- Cherkupally, R., Amballa, H., & Bhoomi, N.R. (2017). *In vitro* screening for enzymatic activity of *Trichoderma* species for biocontrol potential. *Annals of Plant Science*, 6(11): 1784–1789.
- Chesters, C.G.C. (1949). Concerning fungi inhabiting soil. *The British Mycological Society*, 32: 197–216.
- Chet, I. (1987). *Trichoderma* – Applications, Mode of Action and Potential as a Biocontrol Agent of Soilborne Plant Pathogenic Fungi. In I. Chet (Ed.), *Innovative Approaches to Plant Diseases* (pp. 137–160). New York: John Wiley & Sons.
- Chet, I. (1990). Biological Control of Soil-borne Plant Pathogens with Fungal Antagonists in Combination with Soil Treatment. In D. Hornby (Ed.), *Biological Control of Soil-borne Plant Pathogens*. England: CAB International.
- Chet, I., Benhamou, N., & Harman, S. (1998). Mycoparasitism and Lytic enzymes. In G.E. Harman, C.P. Kubick (Eds.), *Trichoderma and Gliocladium* Vol. 2 (pp. 153–172). London: Taylor and Francis.
- Christensen, M., & Backus, M.P. (1961). New or Noteworthy *Penicillia* from Wisconsin soils. *Mycologia*, 53: 451–463.
- Clone Characteristics (2012).
- Cook, R.J. (1988). Biological control and holistic plant-health care in agriculture. *American Journal of Alternative Agriculture*, 3: 51–62.
- Coppings, L.G., & Menn, J.J. (2000). Biopesticides: A review of their action, applications and efficacy. *Pest Management Science*, 56: 651–676.
- Costa, F.G., Zucchi, T.D., & Melo, I.S. (2013). Biological control of phytopathogenic fungi by endophytic actinomycetes isolated from maize (*Zea mays* L.). *An International Journal of Brazilian Archives of Biology and Technology*, 56(6): 948–955.
- Daniel, G. (2014). Fungal and Bacterial Biodegradation: White Rots, Brown Rots, Soft Rots, and Bacteria. In T. Schultz et al. (Eds.), *Deterioration and Protection of Sustainable Biomaterials* (pp. 23–54). Washington: ACS Symposium Series, American Chemical Society.

- de los Santos-Villalobos, S., Guzmán-Ortiz, D.A., Gomez-Lim, M.A., Délanofrier, J.P., de-Folter, S., Sánchez-Garíá, P., et al. (2013). Potential use of *Trichoderma asperellum* (Samuels, Liechfeldt et Nirenberg) T8a as a biological control agent against anthracnose in mango (*Mangifera indica* L.). *Biological Control*, 64: 37–44.
- de Santiago, A., García-López, A.M., Quintero, J.M., Avilés, M., & Delgado, A. (2013). Effect of *Trichoderma asperellum* strain T34 and glucose addition on iron nutrition in cucumber grown on calcareous soils. *Soil Biology and Biochemistry*, 57: 598–605.
- De Souza, T.J., Bailey, B.A., Pomella, A.W.B., Erbe, E.F., Murphy, C.A., Bae, H., et al. (2008). Colonization of cacao seedlings by *Trichoderma stromaticum*, a mycoparasite of the witches' broom pathogen, and its influence on plant growth and resistance. *Biological Control*, 46: 36–45.
- Dede, A.P.O., Akpaja, E.O., & Galillee, J.E. (2011). Effect of pH on the growth of the white root rot pathogen, *Rigidoporus lignosus* (Klotzsch) Imazeki, on selected para rubber sustaining soils in Nigeria. *African Scientist*, 12(3): 175–179.
- Dennis, C., & Webster, J. (1971a). Antagonism properties of species groups of *Trichoderma*, III. Hyphal interaction. *Transactions British Mycological Society*, 57: 363–369.
- Dennis, C., & Webster, J. (1971b). Antagonistic properties of species of groups of *Trichoderma* II. Production of volatile antibiotics. *Transactions of British Mycological Society*, 57: 41–48.
- Desai, S., Reddy, M.R., & Kloepper, J.W. (2002). Comprehensive Testing of Biocontrol Agents. In S.S. Gnanamanickam (Ed.), *Biological Control of Crop Diseases* (pp. 387–420). New York: Marcel Dekker Inc.
- Dixit, R., Singh, R.B., & Singh, H.B. (2015). Screening of antagonistic potential and plant growth promotion activities of *Trichoderma* spp. and fluorescent *Pseudomonas* spp. isolates against *Sclerotinia sclerotiorum* causing stem rot of French bean. *Legume Research*, 38(3): 375–381.
- Domsch, K.H., Gams, W., & Anderson, T-H. (1993). *Compendium of Soil Fungi*. Eching: IHW-Verlag.
- Duke, J.A. (1983). Handbook of Energy Crops. Retrieved from http://www.hort.purdue.edu/newcrop/duke_energy/Hevea_brasiliensis.html
- Eicker, A. (1969). Microfungi from surface soil of forest communities in Zululand. *The British Mycological Society*, 53: 381–392.

- Eilenberg, J., Hajek, A., & Lomer, C. (2001). Suggestions for unifying the terminology in biological control. *BioControl*, 46: 387–400.
- El-Hassan, S.A., Gowen, S.R., & Pembroke, B. (2013). Use of *Trichoderma hamatum* for biocontrol of lentil vascular wilt disease: efficacy, mechanisms of interaction and future prospects. *Journal of Plant Protection Research*, 53(1): 12–26.
- El-Katatny, M.H., Gudelj, M., Robra, K.H., Elnaghy, M.A., & Gubitz, G.M. (2001). Characterization of a chitinase and an endo- β -1,3-glucanase from *T. harzianum* Rifai T-24 involved in control of the phytopathogen *Sclerotium rolfsii*. *Applied Microbiology and Biotechnology*, 56: 137–143.
- El-Katatny, M.S. (2004). Inorganic phosphate solubilisation by free or immobilized *Trichoderma harzianum* cells in comparison with some other soil fungi. *Egyptian Journal of Biotechnology*, 17: 1338–1353.
- El-Komy, M.H., Saleh, A.A., Eranthodi, A., & Molan, Y.Y. (2015). Characterization of novel *Trichoderma asperellum* isolates to select effective biocontrol agents against tomato Fusarium wilt. *Plant Pathology Journal*, 31(1): 50–60.
- Elad, Y., Chet, I., & Henis, Y. (1982). Degradation of plant pathogenic fungi by *Trichoderma harzianum*. *Canadian Journal of Microbiology*, 28: 719–725.
- Eric, S., & David, S.H. (2007). Basidiomycota. The Club Fungi. Version 20 April 2007. <http://tolweb.org/Basidiomycota/20520/2007.04.20> in The tree of Life Web Project, <http://tolweb.org/>
- Faheem, A., Razdan, V.K., Mohiddin, F.A., Bhat, K.A., & Sheikh, P.A. (2010). Effect of volatile metabolites of *Trichoderma* spp. against seven fungal plant pathogens in vitro. *Journal of Phytochemistry*, 2(10): 34–37.
- FAO. (2010, October 25). Crop – rubber. Retrieved from <http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>
- FAO. (2014, May 26). Diseases of rubber an overview. Retrieved from <http://www.fao.org/docrep/015/i2730e/i2730e05.pdf>
- Farhana, A.H.K.F., Razak, S.B.A., Vu Thanh, T.A., & Zakaria, L. (2017). Morphological features of *Rigidoporus microporus* isolated from infected Malaysian rubber clones. *Malaysian Journal of Microscopy*, 13: 17–23.
- Farrow, W.M. (1954). Tropical soil fungi. *Mycologia*, 46: 632–646.
- Fatma, F.M. (2003). Distribution of fungi in the sandy soil in Egyptian beaches. *Pakistan Journal of Biological Science*, 6(10): 860–866.

- Fokkema, N.J. (1978). Fungal antagonism in the phyllosphere. *Annals of Applied Biology*, 89: 115–117.
- Francis, W.M.R.S., Frederick, J., Chris, S., Craig, H., & Mark, S. (2012). Evaluation of an antagonistic *Trichoderma* strain for reducing the rate of wood decomposition by the white rot fungus *Phellinus noxius*. *Biological Control*, 61: 160–168.
- Fravel, R.D. (2005). Commercialization and implementation of biocontrol. *Annual Review of Phytopathology*, 43: 337–359.
- Frost, A. & Sullivan, W. (2009). Overview: Malaysian Agricultural Biotechnology. The Malaysian Agricultural Biotechnology Sector. Retrieved from http://www.bioeconomycorporation.my/wp-content/uploads/2011/11/publications/White_Paper_Agricultural.pdf
- Gade, R.M., Armakar, S.V., & Wardhe, S. (2009). Effect of soil types and nutritional factors on growth and sporulation of *Trichoderma* species. *Annals of Plant Protection and Science*, 17: 111–113.
- Gafni, A., Calderon, C.E., Harris, R., Buxdorf, K., Dafa-Berger, A., Zeilinger-Reichert, E., et al. (2015). Biological control of the cucurbit powdery mildew pathogen *Podosphaera xanthii* by means of the epiphytic fungus *Pseudozyma aphidis* and parasitism as a mode of action. *Frontiers in Plant Science*, 6: 132. Doi: [10.3389/fpls.2015.00132](https://doi.org/10.3389/fpls.2015.00132)
- Gajera, H.P., Bambharolia, R.P., Patel, S.V., Khatrani, T.J., & Goalkiya, B.A. (2012). Antagonism of *Trichoderma* spp. against *Macrophomina phaseolina*: Evaluation of coiling and cell wall degrading enzymatic activities. *Journal of Plant Pathology and Microbiology*, 3: 149.
- Galliano, H., Gas, G., & Boudet, A.M. (2006). Lignin biodegradation by cultures of *Rigidoporus lignosus* in solid state conditions. *FEMS Microbiology Letters*, 67(3): 295–299.
- Geiger, J.P., Rio, B., Nicole, M., & Nandris, D. (1986). Biodegradation of *Hevea brasiliensis*. I. Physiological and biochemical aspects of host aggression. *European Journal of Forest Pathology*, 16: 22–37.
- Ghisalberti, E.L., & Rowland, C.Y. (1993). Antifungal metabolites from *Trichoderma harzianum*. *Journal of Natural Products*, 56: 1799–1804.
- Ghulam, H.D. (2010). *Soil Microbiology and Biochemistry*. Delhi: Jai Bharat Printing Press.
- Gil, S.V., Pastor, S., & March, G. J. (2009). Quantitative isolation of biocontrol agents *Trichoderma* spp., *Gliocladium* spp. and actinomycetes from soil with culture media. *Microbiological Research*, 164: 196–205.

- Gravel, V., Antoun, H., & Tweddell, R.J. (2007). Growth stimulation and fruit yield improvement of greenhouse tomato plants by inoculation with *Pseudomonas putida* or *Trichoderma atroviride*: possible role of indole acetic acid (IAA). *Soil Biology and Biochemistry*, 39: 1968–1977.
- Guillem, S., Manuel, A., Eva, C., Celia, B., & Isabel, T. (2013). Effectiveness of biological control of *Phytophthora capsici* in pepper by *Trichoderma asperellum* strain T34. *Phytopathologia Mediterranea*, 52(1): 77–83.
- Guyot, J., & Flori, A. (2002). Comparative study for detecting *Rigidoporus lignosus* on rubber trees. *Crop Protection*, 21(6): 461–466.
- Haider, M.H., Imad, H.H., & Omar, A.I. (2016). Antimicrobial activity and apectral chemical analysis of methanolic leaves extract of *Adiantum capillus-veneris* using GC-MS and FTIR Spectroscopy. *International Journal of Pharmacognosy and Phytochemical Research*, 8(3): 369-385.
- Handelsman, J., & Stabb, E.V. (1996). Biocontrol of soilborne plant pathogens. *Plant Cell*, 8(10): 1855–1869.
- Harman, G.E. (2000). Myths and dogmas of biocontrol changes in perceptions derived from research on *Trichoderma harzianum* T-22. *Plant Disease*, 84: 377–393.
- Harman, G.E. (2006). Overview of mechanisms and uses of *Trichoderma* spp. *Phytopathology*, 96: 190–194.
- Harman, G.E., Howell, C.R., Viterbo, A., Chet, I., & Lorito, M. (2004). *Trichoderma* species: opportunistic, avirulent plant symbionts. *Nature Review Microbiology*, 2: 43–56.
- Hashim, I., & Azaldin, M.Y. (1985). Interaction of sulphur with soil pH and root diseases of *Hevea* rubber. *Journal of the Rubber Research Institute of Malaysia*, 33(2): 59–69.
- Hashim, I., & Malik, A.Z. (2006). Research on white root disease of *Hevea* achievements and future direction. Paper presented in International Workshop on White Root Disease of *Hevea*, Salatiga, Indonesia. 28 November 2006, pp. 29-32.
- Herath, H.H.M.A.U., Wijesundera, R.L.C., Chandrasekharan, N.V., & Wijesundera, W.S.S. (2017). Exploration of Sri Lankan soil fungi for biocontrol properties. *African Journal of Biotechnology*, 16(20): 1168–1175.
- Hettiarachchi, R.P., Dharmakeerthi, R.S., Jayakody, A.N., Seneviratne, G., de Silva, E., Gunathilake, T., et al. (2014). Effectiveness of fungal bacterial interactions as biofilmed biofertilizers on enhancement of root growth of

- Hevea* seedlings. *Journal of Environmental Professionals Sri Lanka*, 3(2): 25–40.
- Hightley, L.T. (1997). Control of wood decay by *Trichoderma (Gliocladium) virens* I. Antagonistic properties. *Material and organism*, 31(2): 79–89.
- Hjeljord, L., & Tronsmo, A. (1998). *Trichoderma* and *Gliocladium* in Biological Control: An Overview. In G.E. Harman, C.P. Kubicek (Eds.), *Trichoderma and Gliocladium: Basic Biology, Taxonomy and Genetics Vol. II* (pp. 131-151). Bristol: Taylor & Francis.
- Holiday, P. (1980). *Fungal Diseases of Tropical Crops*. United Kingdom: Cambridge University Press. 495 p.
- Hood, A.I. (2006). The mycology of the basidiomycetes. Proceeding from Heart Rot and Root Rot in Tropical Acacia Plantation. Yogyakarta, Indonesia.
- Hoorman, J.J. (2011). The role of soil fungus. Fact Sheet. *Agriculture and Natural Resources, SAG-14-11*: 1–6.
- Howell, C.R. (2003). Mechanisms employed by *Trichoderma* species in the biological control of plant diseases: the history and evolution of current concepts. *Plant Disease*, 87: 4–10.
- Hoyos-Carvajal, L., Orduz, S., & Bissett, J. (2009). Growth stimulation in bean (*Phaseolus vulgaris* L.) by *Trichoderma*. *Biological Control*, 51: 409–416.
- Hubballi, M., Nakkeeran, S., Raguchander, T., Anand, T., & Samiyappan, R. (2010). Effect of environmental conditions on growth of *Alternaria alternata* causing leaf blight of Noni. *World Journal of Agricultural Sciences*, 6(2): 171–177.
- Ibrahim, M.D. (2005). *Delivery System of Trichoderma Inoculant for the Control of Rhizoctonia Diseases in Brassica rapa*. (Unpublished Ph.D. thesis). Universiti Putra Malaysia, Malaysia.
- Idwan, S.L., Iraqi, H.A.I., Le Febvre, G., Kiffer, E., & Botton, B. (1992). Screening of some basidiomycetes for biological control of *Rigidoporus lignosus*, a parasite of rubber tree, *Hevea brasiliensis*. *Mycological Research*, 96: 621–625.
- Ikediegwu, F.E.O., & Ubogu, M. (2012). Root zone microflora is responsible for suppressiveness of the white root rot disease in Akwete rubber plantations. *Journal of Plant Pathology and Microbiology*, 3(151): 1–6.
- Inbar, J., & Chet, I. (1995). The role of recognition in the induction of specific chitinases during mycoparasitism. *Microbiology*, 141: 2823–2829.

- Intan, B., Budi, S., & Hananto, H. (2013). Mechanism of antagonism of *Trichoderma* spp. against several soil borne pathogens. *Warta Perkaretan* 2013, 32(2): 74–82.
- IRRDB (2009). *The Effects of Climate Change on NR Cultivation and Productivity*. Paper presented at International Rubber Research and Development, Kuala Lumpur. November 2009.
- Ismail, A.M., Cirvilleri, G., Polizzi, G., Crous, P.W., Groenewald, J.Z., & Lombard, L. (2012). *Lasiodiplodia* species associated with dieback disease of mango (*Mangifera indica*) in Egypt. *Australasian Plant Pathology*, 41(6): 649-660.
- Ismail, B.S., & Quirinus, L. (2000). Mobility and persistence of metolachlor in two common Malaysian Agricultural Soils. *Bulletin of Environmental Contamination and Toxicology*, 65: 530–536.
- Jangid, K., Williams, M.A., Franzluebbers, A.J., Schmidt, T.M., Coleman, D.C., & Whitman, W.B. (2011). Land-use history has a stronger impact on soil microbial community composition than aboveground vegetation and soil properties. *Soil Biology and Biochemistry*, 43(10): 2184–2193.
- Jayarathne, R., Wettasinghe, P.C., Siriwardene, D., & Peiris, P. (2001). Systemic fungicides as a drench application to control white root disease of rubber. *Journal of Rubber Research Institute of Sri Lanka*, 84: 1–17.
- Jayasinghe, C.K. (2001). *Check List of Rubber Pathogens in Sri Lanka*. Sri Lanka: National Science Foundation.
- Jayasinghe, C.K., & Wettasinghe, J.L.P.C. (1998). Cultural characteristics and reproductive morphology of *Geotrichum* sp.: Guide to distinguish *Geotrichum* from *Rigidoporus*. *Journal of the Rubber Research Institute of Sri Lanka*, 81: 23–28.
- Jayasuriya, K.E. (2004). Factors affecting disease tolerance of rubber tree and research needs for developing disease tolerant genotypes for the sustainability of rubber industry. *Bulletin of Rubber Institute of Sri Lanka*, 45: 1–10.
- Jayasuriya, K.E., & Deacon, J.E. (1995). *In vitro* interactions between *Rigidoporus lignosus*, the cause of white root disease of rubber and some potentially antagonistic fungi. *Journal of Rubber Research Institute of Sri Lanka*, 76: 36–54.
- Jayasuriya, K.E., Deacon, J.W., & Fernando, T.H.P.S. (1996). *In vitro* antagonism caused by some species of fungi on *Rigidoporus lignosus*. *Journal of Rubber Research Institute of Sri Lanka*, 78: 89–101.

- Jayasuriya, K.E., & Thennakoon, B.I. (2007). Biological control of *Rigidoporus microporus*, the cause of white root disease in rubber. *Ceylon Journal of Science (Biological Science)*, 36(1): 9–16.
- Jhariya, S., & Kakkar, A. (2016). Analysis of bioactive components from ethyl acetate and ethanol extract of *Mucuna pruriens* Linn. seeds by GC-MS technique. *Journal of Chemical and Pharmaceutical Research*, 8(8): 403–409.
- Jiang, H., Zhang, L., Zhang, J.-Z., Ojaghian, M.R., & Hyde, K.D. (2016). Antagonistic interaction between *Trichoderma asperellum* and *Phytophthora capsici* in vitro. *Journal of Zhejiang University (Biomedicine & Biotechnology)*, 17(4): 271–281.
- Jinantara, J. (1995). *Evaluation of Malaysian isolates of Trichoderma harzianum Rifai and Glicocladium virens Miller, Giddens and Foster for the biological control of Sclerotium foot rot of chilli*. (Unpublished Ph.D. thesis). Universiti Putra Malaysia, Malaysia.
- John, K.P. (1960). Loss of viability of tree root parasites in infected root sections buried in soil. *Journal of Rubber Research Institute Malaysia*, 16: 173–177.
- Joko, P., Titik, N.A., & Radix, S. (2009). The correlations between white rot (*Rigidoporus lignosus* L.) incidence and soil characters of rubber ecosystem in Penumangan Baru, Lampung. *Journal of HPT Tropika*, 9(2): 149–157.
- Junaid, J.M., Dar, N.A., Bhat, T.A., Bhat, A.H., & Bhat, M.A. (2013). Commercial biocontrol agents and their mechanism of action in the management of plant pathogens. *International Journal of Modern Plant and Animal Sciences*, 1: 39–57.
- Kaewchai, S., Lin, F.C., Wang, H.K., & Soyong, K. (2010). Characterization of *Rigidoporus microporus* isolated from rubber trees based on morphology and ITS sequencing. *Journal of Agricultural Technology*, 6(2): 289–298.
- Kaewchai, S., & Soyong, K. (2010). Application of biofungicides against *Rigidoporus microporus* causing white root disease of rubber trees. *Journal of Agricultural Technology*, 6(2): 349–363.
- Kaewchai, S., Wang, H.K., Lin, F.C., Hyde, K.D., & Soyong, K. (2009). Genetic variation among isolates of *Rigidoporus microporus* causing white root disease of rubber trees in Southern Thailand revealed by ISSR markers and pathogenicity. *African Journal of Microbiology Research*, 3: 641–648.

- Kamala, T., Indira Devi, S., Chandradev Sharma, K., & Kennedy, K. (2015). Phylogeny and taxonomical investigation of *Trichoderma* spp. from Indian region of Indo-Burma biodiversity hot spot region with special reference to Manipur. *BioMed Research International*, 1–21.
- Kapri, A., & Tewari, L. (2010). Phosphate solubilization potential and phosphatase activity of rhizospheric *Trichoderma* spp. *Brazilian Journal of Microbiology*, 41(3): 787–795.
- Kent, A.D., & Triplett, E.W. (2002). Microbial communities and their interactions in soil and rhizosphere ecosystems. *Annual Review of Microbiology*, 56: 211–236.
- Keswani, C., Bisen, K., Chitara, M.K., Sarma, B.K., & Singh, H.B. (2017). Exploring the Role of Secondary Metabolites of *Trichoderma* in Tripartite Interaction with Plant and Pathogens. In JS Singh, G Seneviratne (Eds.), *Agro-Environmental Sustainability* (pp. 63–79). Cham: Springer.
- Khan, M.S., Zaidi, A., Wani, P.A., Ahemad, M., & Oves, M. (2009). Functional Diversity among Plant Growth-promoting Rhizobacteria. In M.S. Khan, A. Zaidi, J. Musarrat (Eds.), *Microbial Strategies for Crop Improvement* (pp. 105–132). Berlin: Springer.
- Khetan, S.K. (2001). *Microbial Pest Control*. New York: Markel Dekker Inc.
- Kiam, T.S. (2002). Forest plantation development in Malaysia and the potential of rubberwood as an important source of timber in the future. In: Proceedings of the International Conference on Timber Plantation Development. FAO, Manila.
- Kim, B.S., & Hwang, B.K. (2007). Microbial fungicides in the control of plant diseases. *Journal of Phytopathology*, 155: 641–653.
- Kim, S.J., & Kremer, R.J. (2005). Scanning and transmission electron microscopy of root colonization of morning glory (*Ipomoea* spp.) seedlings by rhizobacteria. *Symbiosis*, 39: 117–124.
- Kiyono, Y., Furuya, N., Fujita, N., Sato, T., Matsumoto, M., Bounthabandit, S., & Sanonty, S. (2014). Can converting slash-and-burn agricultural fields into rubber tree (*Hevea brasiliensis*) plantations provide climate change mitigation? A case study in northern Laos. *Bulletin of the Forestry and Forest Products Research Institute*, 13(3), 79–88. (No.432).
- Knudsen, I.M.B., Hockenhull, J., Funck Jensen, D., Gerhardson, B., Hökeberg, M., Tahvonen, R., et al. (1997). Selection of biological control agents for controlling soil and seed-borne diseases in the field. *European Journal of Plant Pathology*, 103: 775–784.

- Köberl, M., Dita, M., Martinuz, A., Staver, C., & Berg, G. (2017). Members of Gammaproteobacteria as indicator species of healthy banana plants on *Fusarium* wilt-infested fields in Central America. *Scientific Reports*, 7: 45318. Doi: [10.1038/srep45318](https://doi.org/10.1038/srep45318)
- Korsten, L., De-Jager, E.S., De-Villers, E.E., Lourens, A., Kotze, J.M., & Wehner, F.C. (1995). Evaluation of bacterial epiphytes isolated from avocado leaf and fruit surfaces for biocontrol of avocado postharvest diseases. *Plant Disease*, 79: 1149–1156.
- Kredics, L., Antal, Z., Manczinger, L., Szekeres, A., Kevel, F., & Nagy, E. (2003). Influence of environmental parameters on *Trichoderma* strains with biocontrol potential. *Food Technology and Biotechnology*, 41: 37–42.
- Kumar, P.S., & Singh, L. (2009). *Lasiodiplodia theobromae* is a mycoparasite of a powdery mildew pathogen. *Mycobiology*, 37(4): 308–309.
- Kumar, S., Stecher, G., & Tamura, K. (2016). MEGA7: Molecular Evolutionary Genetics Analysis version 7.0 for bigger datasets. *Molecular Biology and Evolution*, 33: 1870–1874.
- Laha, G.S., Singh, R.P., & Verma, J.P. (1996). Role of Growth Promoting Rhizobacteria in Plant Disease Management. In V.P. Agnihorti, O. Prakash, R. Kishun, A.K. Misra (Eds.), *Disease Scenario in Crop Plants, Vol. II-Cereals, Pulses, Oilseeds and Cash Crops* (pp. 233–241). Delhi, India: International Books and Periodicals.
- Lalngaihawmi, & Bhattacharyya, A. (2019). Study on the different modes of action of potential *Trichoderma* spp. from banana rhizosphere against *Fusarium oxysporum* f. sp. *cubense*. *International Journal of Current Microbiology and Applied Sciences*, 8(1): 1028–1040.
- Law, L. (2009). *Hevea brasiliensis*, the Rubber Tree. Retrieved from <http://www.ethnoleaflets.com/leaflets/rubber2.htm/7-10-09>.
- Lecomte, C., Alabouvette, C., Edel-Hermann, V., Robert, F., & Steinberg, C. (2016). Biological control of ornamental plant diseases caused by *Fusarium oxysporum*: a review. *Biological Control*, 101: 17–30.
- Lehner, S.M., Atanasova, L., Neumann, N.K.N., Krska, R., Lemmens, M., Druzhinina, I.S., & Schuhmachera, R. (2013). Isotope-assisted screening for iron-containing metabolites reveals a high degree of diversity among known and unknown siderophores produced by *Trichoderma* spp. *Applied and Environmental Microbiology*, 79(1): 18–31.
- Lewis, J.A., & Papavizas, G.C. (1991). Biocontrol of plant diseases: the approach for tomorrow. *Crop Protection*, 10: 95–105.

- Li, T., Wang, H-Y., Xia, X-B., Cao, S-J., Yao, J-G., & Zhang, L-L. (2018). Inhibitory effects of components from root exudates of Welsh onion against root knot nematodes. *PLoS One*, 13(7): e0201471.
- Lima, L.H.C., Ulhoa, C.J., Fernandes, A.P., & Felix, C.R. (1997). Purification of a chitinase from *Trichoderma* sp. and its action on *Sclerotium rolfsii* and *Rhizoctonia solani* cell walls. *Journal of General and Applied Microbiology*, 43: 31–37.
- Lin, X., Feng, Y., Zhang, H., Chen, R., Wang, J., Zhang, J., et al. (2012). Long-term balanced fertilization decreases arbuscular mycorrhizal fungal diversity in an arable soil in north China revealed by 454 pyrosequencing. *Environmental Science and Technology*, 46(11): 5764–5771.
- Lin, Y-H., Chang, J-Y., Liu, E-T., Chao, C-P., Huang, J-W., & Linda Chang, P-F. (2009). Development of a molecular marker for specific detection of *Fusarium oxysporum* f. sp. *cubense* race 4. *European Journal of Plant Pathology*, 123: 353–365.
- Linderman, R.G., Moore, L.W., Baker, K.F., & Cooksey, D.A. (1983). Strategies for detecting and characterizing systems for biological control of soilborne plant pathogens. *Plant Disease*, 67: 1058–1064.
- Liyanage, G.W., Liyanage, A. de S., Peries, O.S., & Halangoda, L. (1977). Studies on the variability and pathogenicity of *Rigidoporus lignosus*. *Journal of the Rubber Research Institute of Sri Lanka*, 54: 363–372.
- Lorito, M., Woo, S.L., Harman, G.E., & Monte, E. (2010). Translational research on *Trichoderma*: from 'omics to the field. *Annual Review of Phytopathology*, 48: 395–417.
- Lugtenberg, B., & Kamilova, F. (2009). Plant-growth-promoting rhizobacteria. *Annual Review of Microbiology*, 63: 541–556.
- Magnuson, J.K., & Lasure, L.L. (2002). Fungal Diversity in Soils as Assessed by Direct Culture and Molecular Techniques. Paper presented at the 102nd General Meeting of the America Society for Microbiology, Salt Lake City. May 2002.
- Mahmoud, H.El-K., Amgad, A.S., Anas, E., & Younes, Y.M. (2015). Characterization of novel *Trichoderma asperellum* isolates to select effective biocontrol agents against tomato fusarium wilt. *The Plant Pathology Journal*, 31(1): 50–60.
- Marco, J.L.M., & Felix, C.R. (2007). Purification and characterization of a β -glucanase produced by *Trichoderma harzianum* showing biocontrol potential. *Brazilian Archives of Biology and Technology*, 1: 21–29.

- Matthias, H. (2014). The rising threat of fungicide resistance in plant pathogenic fungi: *Botrytis* as a case study. *Journal of Chemical Biology*, 7(4): 133–141.
- Mausam, V., Satinder, K.B., Tyagi, R.D., Surampalli, R.Y., & Val'ero, J.R. (2007). Antagonistic fungi, *Trichoderma* spp.: Panoply of biological control. *Biochemical Engineering Journal*, 37: 1–20.
- Mbarga, J.B., Martijn, G.T.H., Kuate, J., Adiobo, A., Ngonkeu, M.E.L., Ambang, Z., et al. (2012). *Trichoderma asperellum*: A potential biocontrol agent for *Pythium myriotylum*, causal agent of cocoyam (*Xanthosoma sagittifolium*) root rot disease in Cameroon. *Crop Protection*, 36: 18–22.
- McMahon, P. (2012). Effect of Nutrition and Soil Function on Pathogens of Tropical Tree Crops. In C.J. Cumagun (Ed.), *Plant Pathology*. InTech, ISBN 978-953-51-0489-6.
- Mendoza, J.L.H., Pérez, M.I.S., Prieto, J.M.G., Velásquez, J.D.Q., Olivares, J.G.G., & Langarica, H.R.G. (2015). Antibiosis of *Trichoderma* spp. strains native to northeastern Mexico against the pathogenic fungus *Macrophomina phaseolina*. *Brazilian Journal of Microbiology*, 46(4): 1093–1101.
- Meyer, S.L.F., & Roberts, D.P. (2002). Combination of bio-control agents for management of plant-parasitic nematodes and soil borne plant-pathogen fungi. *Journal of Nematology*, 34: 1–8.
- Mohamed, H.M. (2015). Effect of arbuscular mycorrhizal fungus (*Glomus mosseae*) and soil yeasts interaction on root nodulation, n-fixation and growth of faba bean (*Vicia faba*). *Malaysian Journal of Soil Science*, 19: 157–168.
- Mohammed, C.L., Rimbawanto, A., & Page, D.E. (2014). Management of basidiomycete root- and stem-rot diseases in oil palm, rubber and tropical hardwood plantation crops. *Forest Pathology*, 44: 428–446.
- Mohd Farid, A., Lee, S.S., Maziah, Z., & Patahayah, M. (2009). Pathogenicity of *Rigidoporus microporus* and *Phellinus noxius* against four major plantation tree Species in Peninsular Malaysia. *Journal of Tropical Forest Science*, 21(4): 289–298.
- Mohiddin, F.A., Bashir, I., Padder, S.A., & Hamid, B. (2017). Evaluation of different substrates for mass multiplication of *Trichoderma* species. *Journal of Pharmacognosy and Phytochemistry*, 6(6): 563–569.
- Mohiddin, F.A., Bhat, F.A., Bhat, K.A., Bhat, Z.A., Bhat, M.A., Hamid, B., et al. (2018). Development of *Trichoderma* based bioformulations for the management of chilli wilt. *Journal of Pharmacognosy and Phytochemistry*, 7(1): 2118–2122.

- Monkai, J., Hyde, K.D., Xu, J., & Mortimer, P.E. (2016). Diversity and ecology of soil fungal communities in rubber plantations. *Fungal Biology Reviews* (2016). Doi: [10.1016/j.fbr.2016.08.003](https://doi.org/10.1016/j.fbr.2016.08.003)
- Mooibroek, H., & Cornish, K. (2000). Alternative sources of natural rubber. *Applied Microbiology and Biotechnology*, 53(4): 355–365.
- Mukherjee, P.K. (2011). Genomics of biological control – whole genome sequencing of two mycoparasitic *Trichoderma* spp. *Current Science*, 101(3): 268.
- Murthy, N., & Bleakley, B. (2012). Simplified method of preparing colloidal chitin used for screening of chitinase-producing microorganisms. *The Internet Journal of Microbiology*, 10(2): 1–5.
- Nagamani, P., Bhagat, S., Biswas, M.K., & Viswanath, K. (2017). Effect of volatile and non-volatile compounds of *Trichoderma* spp. against soil borne diseases of Chickpea. *International Journal of Current Microbiology and Applied Science*, 6(7): 1486–1491.
- Nahar, K., & Gretzmacher, R. (2011). Response of shoot and root development of seven tomato cultivars in hydroponic system under water stress. *Academic Journal of Plant Sciences*, 4: 57–63.
- Nandris, D., Nicole, M., & Geiger, J.P. (1987). Root rot diseases of rubber trees. *Plant Disease*, 71: 298–306.
- Narayanan, C., & Mydin, K.K. (2012). Breeding for disease resistance in *Hevea* spp. -Status, potential threats, and possible strategies. Proceedings from the 4th International Workshop on Genetics of Host-Parasite Interactions in Forestry: 240–247.
- Nareeluk, N., Chakrapong, R., & Rungroch, S. (2015). Utilization of rhizospheric *Streptomyces* for biological control of *Rigidoporus* sp. causing white root disease in rubber tree. *European Journal of Plant Pathology*, 142: 93–105.
- Natural Rubber Statistics (2018). Retrieved March 22, 2019 from <http://www.lgm.gov.my/nrstat/nrstats.pdf>.
- Ng, K.J., & Yap, T.H. (1990). The effect of triadimefon and triadimenol for controlling white root disease of rubber. *Proceedings of 3rd International Conference of Plant Protection in the Tropics*, 2, 31–35.
- Ng, L.C., Ngadin, A., Azhari, M., & Zahari, N.A. (2015). Potential of *Trichoderma* spp. as biological control agents against Bakanae pathogen (*Fusarium fujikuroi*) in rice. *Asian Journal of Plant Pathology*, 9: 46–58.

- Nicole, M., Geiger, J.P., & Nandris, D. (1986). Penetration and degradation of suberized cells of *Hevea brasiliensis* infected with root rot fungi. *Physiology Molecular of Plant Pathology*, 28: 181–185.
- Nicole, M., Geiger, J.P., & Nandris, D. (1987). Ultrastructural aspects of rubber tree root rot diseases. *European Journal of Forest Pathology*, 17: 1–11.
- Nicole, R.M., & Benhamou, N. (1991). Ultrastructural localization of chitin in cell walls of *Rigidoporus lignosus*, the white-rot fungus of rubber tree roots. *Physiology and Molecular Plant Pathology*, 39: 415–431.
- Nissapa, A., & Chuenchit, S. (2011). Economic Loss Assessments from White Root Disease in Rubber in Southern Thailand. Report of Faculty of Natural Resource, Prince of Songkla University, Thailand, p. 277.
- Noordin, W.D., Shafar, J.M. & Che Fauziah, I. (2012). Assessment of selected *Hevea brasiliensis* (RRIM 2000 Series) seeds for rootstocks production. *African Journal of Agricultural Research*, 7(21): 3209–3216.
- Noori, M.S.S., & Saud, H.M. (2012). Potential plant growth-promoting activity of *Pseudomonas* sp. isolated from paddy soil in Malaysia as biocontrol agent. *Journal of Plant Pathology and Microbiology*, 3. Doi: [10.4172/2157-7471.1000120](https://doi.org/10.4172/2157-7471.1000120)
- Ogbebor, N.O., Adekunle, A.T., Eghafona, N.O., & Ogboghodo, A.I. (2010). *Ganoderma psuedoferreum*: Biological control possibilities with microorganisms isolated from soils of rubber plantations in Nigeria. *African Journal of General Agriculture*, 6: 301–305.
- Ogbebor, N.O., Adekunle, A.T., Eghafona, O.N., & Ogboghodo, A.I. (2015). Biological control of *Rigidoporus lignosus* in *Hevea brasiliensis* in Nigeria. *Fungal Biology*, 119: 1–6.
- Oghenekaro, A.O., Daniel, G., & Asiegbu, F.O. (2015). The saprotrophic wood-degrading abilities of *Rigidoporus microporus*. *Silva Fennica*, 49(4): article id 1320. <http://dx.doi.org/10.14214/sf.1320>
- Oghenekaro, A.O., Miettinen, O., Omorusi, V.I., Evueh, G.A., Farid, M.A., Gazis, R., et al. (2014). Molecular phylogeny of *Rigidoporus microporus* isolates associated with white rot disease of rubber trees (*Hevea brasiliensis*). *Fungal Biology*, 118(5-6): 495–506.
- Okigbo, R.N., & Ikediugwu, F.E.O. (2000). Studies on biological control of postharvest rot of yams (*Dioscorea* spp.) with *Trichoderma viride*. *Journal of Phytopathology*, 148(6): 351–355.

- Omo-Ikerodah, E.E., Omorusi, V.I., & Mokwunye, M.U.B. (2012). Challenges and progress in the control of white root rot disease of *Hevea brasiliensis* in Africa. *World Rural Observations 2012*, 4(1): 1–2.
- Omorusi, V.I. (2012). Chapter 5: Effects of White Root Rot Disease on *Hevea brasiliensis* (Muell. Arg.) – Challenges and Control Approach. *Plant Science*: 139–152.
- Onokpise, O.U. (2004). Natural rubber (*Hevea brasiliensis* Muell. Arg) germplasm collection in the Amazon Basin, Brazil: a retrospective. *Economic Botany*, 58: 544–555.
- Ordentlich, A.Y., Elad, Y., & Chet, I. (1988). The role of chitinase of *Serratia macescens* in biocontrol of *Sclerotium rolfsii*. *Phytopathology*, 78: 84–88.
- Otadoh, J.A., Okoth, S.A., Ochanda, J., & Kahindi, J.P. (2011). Assessment of *Trichoderma* isolates for virulence efficacy on *Fusarium oxysporum* f. sp. *phaseoli*. *Tropical and Subtropical Agroecosystems*, 13: 99–107.
- Otoide, V.O. (1978). Further observations on the pretreatment of forest trees for root disease control. In *Hevea* plantings. Paper presented at RRIN Seminar, 7 pp.
- Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., & Simons, A. (2009). Agroforestry Database: a tree reference and selection guide version 4.0 (http://www.worldagroforestry.org/treedb/AFTPDFS/Hevea_brasiliensis.PDF).
- Pal, K., & Gardener, B.M. (2006). Biological control of plant pathogens. The Plant Health Instructor. Doi: 10.1094/PHI-A-2006-1117-02. APSnet: 1–25.
- Pandey, S., Shahid, M., Srivastava, M., Anuradha Singh, A.S., & Kumar, V. (2014). Isolation, purification and characterization of glucanase enzyme from the antagonistic fungus *Trichoderma*. *International Journal of Scientific & Engineering Research*, 5(3): 646–650.
- Pandya, J.R., Sabalpara, A.N., & Chawda, S.K. (2011). *Trichoderma*: a particular weapon for biological control of phytopathogens. *Journal of Agricultural Technology*, 7(5): 1187–1191.
- Papavizas, G.C. (1985). *Trichoderma* and *Gliocladium*: Biology, ecology, and potential for biological control. *Annual Review of Phytopathology*, 23: 23–54.
- Pareek, R.P., & Gaur, A.C. (1973). Release of phosphorus from tricalcium phosphate and rock phosphate by organic acids. *Current Science*, 43: 278–279.

- Patten, C.L., & Glick, B.R. (1996). Bacterial biosynthesis of indole-3- acetic acid. *Canadian Journal of Microbiology*, 42: 207–220.
- Pedraza, J.M.T., Aguilera, J.A.M., Díaz, C.N., Ortiz, D.T., Monter, A.V., & Mir, S.G.L. (2013). Control of *Lasiodiplodia theobromae*, the causal agent of dieback of sapote mamey [*Pouteria sapota* (Jacq.) H. E. Moore and Stearn] grafts in Mexico. *Revista Fitotecnia Mexicana*, 36(3): 233–238.
- Peng, G., McGregor, L., Lahlali, R., Gossen, B.D., Hwang, S.F., Adhikari, K.K., et al. (2011). Potential biological control of clubroot on canola and crucifer vegetable crops. *Plant Pathology*, 60: 566–574.
- Peries, O.S. (1965). Recent developments in the control of the diseases of the *Hevea* rubber tree. *Quarter Journal Rubber Research Institute of Ceylon*, 41: 33–43.
- Peries, O.S., Liyanage, A.D.S., & Liyanage, N.I.S. (1979). Fungi associated with rubber growing soils in Sri Lanka. *Journal of Rubber Research Institute of Sri Lanka*, 56: 9–20.
- Peries, O.S., & Liyanage, N.I.S. (1983). The use of sulphur for the control of white root disease caused by *Rigidoporus lignosus*. *Journal of Rubber Research Institute of Sri Lanka*, 61: 35–40.
- Petrisor, C., Paica, A., & Constantinescu, F. (2016). Influence of abiotic factors on *in vitro* growth of *Trichoderma* strains. *Proceedings of the Romanian Academy Series B*, 18(1): 11–14.
- Ploetz, R.C. (2007). Diseases of tropical perennial crops: challenging problems in diverse environments. *Plant Disease*, 91(6): 644–663.
- Prasad, B.N., & Kumar, M.R. (2011). Effect of non-volatile compounds produced by *Trichoderma* spp. on growth and sclerotial viability of *Rhizoctonia solani*, incident of sheath blight of rice. *Indian Journal of Fundamental and Applied Life Science*, 1(2): 37–42.
- Prasad, M., & Naik, S.T. (2002). Management of root rot and heart rot of *Acacia mangium* Willd. *Karnataka Journal of Agricultural Sciences*, 15: 321–326.
- Priyadarshan, P.M, & Goncalves, P.deS. (2003). *Hevea* gene pool for breeding. *Genetic Resources and Crop Evolution*, 50(1): 101–114.
- Promwee, A. (2011). Role of *Trichoderma* spp. as phosphate solubilizing microorganism. *Thai Journal of Soils and Fertilizers*, 33(1): 17–30.
- Promwee, A., Issarakraisila, M., Intana, W., Chamswarn, C., & Yenjit, P. (2014). Phosphate solubilization and growth promotion of rubber tree

- (*Hevea brasiliensis* Muell. Arg.) by *Trichoderma* Strains. *Journal of Agricultural Science*, 6(9): 8–20.
- Purseglove, J.W. (1977). *Tropical Crops: Dicotyledons*. London: Longman Group.
- Qi, W-Z., & Zhao, L. (2013). Study of the siderophore-producing *Trichoderma asperellum* Q1 on cucumber growth promotion under salt stress. *Journal of Basic Microbiology*, 53: 355–364.
- Qualhato, T.F., Lopes, F.A.C., Steindorff, A.S., Brandaõ, R.S., Jesuino, R.S.A. & Ulhoa, C.J. (2013). Mycoparasitism studies of *Trichoderma* species against three phytopathogenic fungi: evaluation of antagonism and hydrolytic enzyme production. *Biotechnology Letters*, 35(9): 1461–1468.
- Raaijmakers, J.M., Paulitz, T.C., Steinberg, C., Alabouvette, C., & Moënne-Loccoz, Y. (2009). The rhizosphere: a playground and battlefield for soilborne pathogens and beneficial microorganisms. *Plant and Soil*, 321(1-2): 341–361.
- Rafael, L.F.deV., & Elke, J.B.N.C. (2009). Rhizospheric streptomyces as potential biocontrol agents of *Fusarium* and *Armillaria* pine rot and as PGPR for *Pinus taeda*. *Journal of BioControl*, 54: 807–816.
- Rahman, M.A., Begum, M.F., & Alam, M.F. (2009). Screening of *Trichoderma* isolates as a biological control agent against *Ceratocystis paradoxa* causing pineapple disease of Sugarcane. *Mycobiology*, 37: 277–285.
- Rahman, M.M., Ali, M.E., Khan, A.A., Akanda, A.M., Kamal Uddin, Md., Hashim, U., et al. (2012). Isolation, characterization, and identification of biological control agent for potato soft rot in Bangladesh. *The Scientific World Journal*, 2012: 1–6.
- Ram, H.M., & Kendurkar, S.V. (2014). Modes of parasitism between the necrotrophic fungus *Botrytis cinerea* and *Trichoderma* spp. *Journal of Biology, Agriculture and Healthcare*, 4(26): 1–10.
- Rathasingam, J., Ramasamy, G., Ioras, F., Kaner, J., & Lu, W-M. (2012). Production potential of rubberwood in Malaysia: Its economic challenges. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 40(2): 317–322.
- Rawat, R., & Tewari, L. (2011). Effect of abiotic stress on phosphate solubilization by biocontrol fungus *Trichoderma* sp. *Current Microbiology*, 62(5): 1521–1526.
- Raziq, F., & Fox, R.T.V. (2006). The integrated control of *Armillaria mellea* 2. Field experiments. *Biological Agriculture and Horticulture*, 23: 235–249.

- Reed, C.F. (1976). Information summaries on 1000 economic plants. Typescripts submitted to the USDA.
- Rifai, M.A. (1969). A revision of the genus *Trichoderma*. *Mycology Paper*, 116: 1–56.
- Rodesuchit, A. (1998). *White Root Disease [Rigidoporus lignosus (Klotzsch) Imazeki] of the Rubber Tree and a Biological Control Approach*. (Unpublished Master thesis). Prince of Songkhla University, Thailand.
- Rodesuchit, A., Suchatgul, S., Klaewklong, B., & Damnoi, S. (2012). Efficacy of fertilizers to control white root disease of rubber caused by *Rigidoporus microporus* at the early planting stages. *Rubber Thai Journal*, 1: 62–72.
- Rodriguez, H., & Fraga, R. (1999) Phosphate solubilizing bacteria and their role in plant growth promotion. *Biotechnology Advances*, 17: 319–339.
- Rodríguez, J.A.C., Hanafi, M.M., Syed Omar, S.R., & Rafii, Y.M. (2009). Chemical characteristics of representative high aluminium saturation soil as affected by addition of soil amendments in a closed incubation system. *Malaysian Journal of Soil Science*, 13: 13–28.
- Rohilla, S.K., & Salar, R.K. (2012). Isolation and characterization of various fungal strains from agricultural soil contaminated with pesticides. *Research Journal of Recent Sciences*, 1(ISC-2011): 297-303.
- Rosado, A.W.C., Machado, A.R., Freire, F.C.O., & Pereira, O.L. (2016). Phylogeny, identification and pathogenicity of *Lasiodiplodia* associated with postharvest stem-end rot of coconut in Brazil. *Plant Disease*, 100: 561-568.
- Rose, K., & Steinbüchel, A. (2005). Biodegradation of natural rubber and related compounds: Recent insights into a hardly understood catabolic capability of microorganisms. *Applied and Environmental Microbiology*, 71: 2803–2812.
- Rudresh, D.L., Shivaprakash, M.K., & Prasad, R.D. (2005). Tricalcium phosphate solubilizing abilities of *Trichoderma* spp. in relation to P uptake and growth and yield parameters of chickpea (*Cicer arietinum* L.). *Canadian Journal of Microbiology*, 51: 217–222.
- Sadasivam, S., & Manickam, K. (1992). *Biochemical method for Agricultural sciences*. Coimbatore: Wiley Estern Limited.
- Sail, R.M., & Ahmad, M. (2009). *Enhancing Socio-Economy of Rubber Smallholders through Effective Transfer of Technology*. Paper presented at the National Rubber Economic Conference, June 2009, Kuala Lumpur, pp. 134–142.

- Sakpetch, P., H-Kittikun, A., Kuwahara, Y., Komeda, H., & Asano, Y. (2018). Isolation of indigenous antagonistic microorganism to inhibit *Rigidoporus microporus* and other plant pathogens and analysis of the bioactive compounds. *Biological Control*, 124 (2018): 53–60.
- Salisu, M., Daud, N., & Ahmad, I. (2013). Influence of fertilizer rates and soil series on growth performance of natural rubber (*Hevea brasiliensis*) latex timber clones. *Australian Journal of Crop Science*, 7(13): 1998–2004.
- Sallam, N.M.A., Abo-Elyousr, K.A.M., & Hassan, M.A.E. (2008). Evaluation of *Trichoderma* species as biocontrol agents for damping-off and wilt diseases of *Phaseolus vulgaris* L. and efficacy of suggested formula. *Egyptian Journal of Phytopathology*, 36(1-2): 81–93.
- Samuel, L., Yue, K.C., Ng, K.H., & Mohd Effendi, W. (2014). Screening for antimicrobial activity of fungi in soil samples collected from Kubah National Park. *International Journal of Scientific & Technology Research*, 3(2): 1–9.
- Sang, M.K., & Kim, K.D. (2012). The volatile-producing *Flavobacterium johnsoniae* strain GSE09 shows biocontrol activity against *Phytophthora capsici* in pepper. *Journal of Applied Microbiology*, 113: 383–398.
- Santos, A., García, M., Cotes, A.M., & Villamizar, L. (2012). The effect of the formulation on the shelf-life of biopesticides based on two Colombian isolates of *Trichoderma koningiopsis* Th003 and *Trichoderma asperellum* Th034. *Revista Iberoamericana De Micología*, 29: 150–156.
- Sappänen, S.K., Pasonen, H.L., Vauramo, S., Vahala, J., Toikka, M., et al. (2007). Decomposition of the leaf litter and mycorrhiza forming ability of silver birch with a genetically modified lignin biosynthesis pathway. *Applied Soil Ecology*, 36: 100–106.
- Saravanakumar, K., Shanmuga Arasu, V., & Kathiresan, K. (2013) Effect of *Trichoderma* on soil phosphate solubilization and growth improvement of *Avicennia marina*. *Aquatic Botany*, 104: 101–105.
- Sariah, M. (2003). The potential of biological management of basal stem rot of oil palm: Issues, challenges and constraints. *Oil Palm Bulletin*, 47: 1–5.
- Sariah, M., Choo, C.W., Zakaria, H., & Norihan, M.S. (2005). Quantification and characterisation of *Trichoderma* species from different ecosystems. *Mycopathologia*, 159: 113–117.
- Satoh, K., Shimizu, T., Kondoh, H., Hiraguri, A., Sasaya, T., Choi, I-R., et al. (2011). Relationship between symptoms and gene expression induced

by the infection of three strains of rice dwarf virus. *Plos One Journal*, 6(3): e18094. <https://doi.org/10.1371/journal.pone.0018094>

- Satyakala, K., Alladi, A., & Thakur, K.D. (2017). Effect of physiological parameters on growth of *Aspergillus niger* and *Trichoderma harzianum*. *International Journal of Pure and Applied Bioscience*, 5(4): 1808–1812.
- Schwarze, F.W.M.R., Jauss, F., Spencer, C., Hallam, C., & Schubert, M. (2012). Evaluation of an antagonistic *Trichoderma* strain for reducing the rate of wood decomposition by the white rot fungus *Phellinus noxius*. *Biological Control*, 61(2): 160–168.
- Schwyn, B., & Neilands, J.B. (1987). Universal chemical assay for the detection and determination of siderophores. *Analytical Biochemistry*, 160: 47–56.
- Semangun, H. (2000). *Penyakit-penyakit Tanaman Perkebunan di Indonesia*. Yogyakarta: Gadjah Mada Universiti Press.
- Shafar, J.M., & Noordin, W.D. (2011). Performance of *Hevea brasiliensis* on haplic acrisol soil as affected by different source of fertilizer. *International Journal of Applied Science and Technology*, 1(1): 50–53.
- Shareef, H.K., Muhammed, H.J., Hussein, H.M., & Hameed, I.H. (2016). Antibacterial effect of ginger (*Zingiber officinale*) roscoe and bioactive chemical analysis using gas chromatography mass spectrum. *Oriental Journal of Chemistry*, 32(2): 817–837.
- Sharma, Radheshyam, Arunabh, J., & Ramesh, C.D. (2012). A brief review on mechanism of *Trichoderma* fungus use as biological control agents. *International Journal of Innovations in Bio-Sciences*, 2(4): 200–210.
- Shen, Z., Ruan, Y., Chao, X., Zhang, J., Li, R., & Shen, Q. (2015a). Rhizosphere microbial community manipulated by 2 years of consecutive biofertilizer application associated with banana Fusarium wilt disease suppression. *Biology and Fertility of Soils*, 51: 553–562.
- Shen, Z., Ruan, Y., Xue, C., Zhong, S., Li, R., & Shen, Q. (2015b). Soils naturally suppressive to banana Fusarium wilt disease harbor unique bacterial communities. *Plant Soil*, 393: 21–33.
- Shi, L., Mortimer, P.E., Ferry Slik, J.W., Zou, X., Xu, J., Feng, W., et al. (2013). Variation in forest soil fungal diversity along a latitudinal gradient. *Fungal Divers*, 64: 305–315.
- Shigematsu, A., Mizoue, N., Kajisa, T., & Yoshida, S. (2011). Importance of rubberwood in wood export of Malaysia and Thailand. *New Forests*, 41(2): 179–189.

- Siddiquee, S., Cheong, B.E., Taslima, K., Kausar, H., & Hasan, M.M. (2012). Separation and identification of volatile compounds from liquid cultures of *Trichoderma harzianum* by GC-MS using three different capillary columns. *Journal of Chromatographic Science*, 50: 358–367.
- Siddiqui, Z.A., & Mahmood, I. (1996). Biological control of *Heterodera cajani* and *Fusarium udum* on pigeonpea by *Glomus mosseae*, *Trichoderma harzianum* and *Verticillium chlamydosporium*. *Israel Journal of Plant Science*, 44: 49–56.
- Singh, J. (1937). Observations on the microfungi of Punjab soils. *Current Science of India*, 5: 589.
- Situmorang, A., & Budiman, A. (1990). Beberapa Metode Aplikasi Fungisida dalam Pengendalian Penyakit Akar Putih (*Rigidoporus microporus*) pada Tanaman Karet. *Pros. Konf. Nas. Karet. Buku II*: 383–394.
- Sivan, A., & Chet, I. (1986). Biological control of *Fusarium* spp. in cotton, wheat and muskmelon by *Trichoderma harzianum*. *Journal of Phytopathology*, 116: 39–47.
- Soekirman, P., & Budi, S. (2009). Integrated disease management of white root disease on *Hevea* rubber using *Trichoderma* and antagonistic plants. Getas Research Center. Indonesian Rubber Research Institute. In *Disease Management Strategies in Plantations*, Jogjakarta, 4–8 May 2009. AusAID sponsored workshop.
- Soepena, H. (1993). Eradication of white root fungi with *Trichoderma*. *Warta Per karetan (News of Rubber)*, 12: 17–22.
- Soytong, K., Kanokmadhakul, S., Kukongviriyapa, V., & Isobe, M. (2001). Application of *Chaetomium* species (Ketomium ®) as a new broad spectrum biological fungicide for plant disease control: A review article. *Fungal Diversity*, 7: 1–15.
- Speight, M.R., & Wylie, F.R. (2001). *Insects Pests in Tropical Forestry*. United Kingdom: CABI Publishing.
- Srinivasa, N., Sriram, S., Chandu Singh, & Shivashankar, K.S. (2017). Secondary metabolites approach to study the bio-efficacy of *Trichoderma asperellum* isolates in India. *International Journal of Current Microbiology and Applied Sciences*, 6(5): 1105–1123.
- Srinivasan, U., Staines, H.J., & Bruce, A. (1992). Influence of media type on antagonistic modes of *Trichoderma* spp. against wood decay basidiomycetes. *Materia Organica*, 27: 301–321.
- Stoppacher, N., Kluger, B., Zeilinger, S., Krska, R., & Schuhmacher, R. (2010). Identification and profiling of volatile metabolites of the biocontrol

- fungus *Trichoderma atroviride* by HS-SPME-GC-MS. *Journal of Microbiology Methods*, 81(2): 187–193.
- Sujeewa, A.M.N., Kelaniyangoda, D.B., & Nugawela, A. (2013). White Root Disease of *Hevea brasiliensis*, its Morphological Differences and Method of Control (*in-vitro*) in North Western Province. Proceedings of 12th Agricultural Research Symposium, 145–149.
- Susanto, A., Sudharto, P.S., & Purba, P.Y. (2005). Enhancing biological control of basal stem rot disease (*Ganoderma boninense*) in oil palm plantations. *Mycopathologia*, 159: 153–157.
- Suryanto, D., Munthe, R.A., Nurwahyuni, I., & Munir, E. (2017). An assay on potential of local *Trichoderma* spp. to control white root rot disease caused by *Rigidoporus microporus* in rubber plant stump. *Journal of Pure and Applied Microbiology*, 11(2): 717–723.
- Sylvain, P. (2011). Evaluation of the topographic effect on the results of mapping by electrical resistivity method: Application to rubber tree plantation on Ban Non Tun experimental site in north-east of Thailand. <hal-00794616>
- Szekeres, A., Leitgeb, B., Kredics, L., Zsuzsanna, A., Hatvani, L., Manczinger, L., et al. (2005). Peptaibols and related peptaibiotics of *Trichoderma*. *Acta Microbiologica et Immunologica Hungarica*, 52: 137–168.
- Tan, A.M. (1990). *The Present Status of Fungicide Drenching on the Control of White Root Disease of Rubber*. Proceedings of International of Rubber Research and Development Hoard Symposium on Root Diseases of *Hevea*, 1990, China, pp. 47–54.
- Tan, Y., Cui, Y-S., Li, H-Y., Kuang, A-X., Li, X-R., Wei, Y-L., & Ji, X-L. (2017). Rhizospheric soil and root endogenous fungal diversity and composition in response to continuous *Panax notoginseng* cropping practices. *Microbiological Research*, 194: 10–19.
- Tellez-Tellez, M., Fernandez, F.J., & Montiel-Gonzalez, A.M. (2008). Growth and laccase production by *Pleurotus ostreatus* in submerged and solid-state fermentation. *Applied Microbiology Biotechnology*, 81: 675.
- Tronsmo, A., & Hjeljord, L.G. (1998). Biological Control with *Trichoderma* species. In G.S. Boland, L.D. Kuykendall (Eds.), *Plant-microbe Interactions and Biological Control* (pp. 111–124). New York: Marcel Dekker Inc.
- Tsrer, L., Barak, R., & Sneh, B. (2001). Biological control of black scurf on potato under organic management. *Crop Protection*, 20: 145–150.

- Tsuneo, W. (2010). *Pictorial Atlas of Soil and Seed Fungi*. Morphologies of Cultured Fungi and Key to Species, 3rd ed. New York: USA CRC press.
- Ubogu, M. (2013). Assessment of root zone mycoflora of three *Hevea brasiliensis* (Rubber) clones at Akwete plantations and their *in vitro* growth inhibition of *Rigidoporus lignosus*. *European Journal of Experimental Biology*, 3(2): 618–623.
- Upadhyay, R.S., & Rai, B. (1979). Ecological survey of Indian soil fungi with special reference to *Aspergilli*, *Penicillia* and *Trichoderma*. *Revue Ecologie et de Biologie du Sol*, 16: 39–49.
- Úrbez-Torres, J.R., Leavitt, G.M., Guerrero, J.C., Guevara, J., & Gubler, W.D. (2008). Identification and pathogenicity of *Lasiodiplodia theobromae* and *Diplodia seriata*, the causal agents of bot canker disease of grapevines in Mexico. *Plant Disease*, 92: 519–529.
- Vargas-Inciarte, L., Fuenmayor-Arrieta, Y., Luzardo-Méndez, M., Costa-Jardin, M.D., Vera, A., Carmona, D., et al. (2019). Use of different *Trichoderma* species in cherry type tomatoes (*Solanum lycopersicum* L.) against *Fusarium oxysporum* wilt in tropical greenhouses. *Agronomía Costarricense*, 43(1): 85–100.
- Varghese, G. (1972). *Soil Microbiology of Jungle Plantation Habitats in Malaysia*. (Unpublished Ph.D. Thesis). University of Nottingham, England.
- Varsha, K.K., Devendra, L., Shilpa, G., Priya, S., Pandey, A., & Nampoothiri, K.M. (2015). 2,4-Di-tert-butyl phenol as the antifungal, antioxidant bioactive purified from a newly isolated *Lactococcus* sp. *International Journal of Food Microbiology*, 211: 44–50.
- Van Driesche, R.G., & Bellows, T.S.Jr. (1996). Pest Origins, Pesticides and the History of Biological Control. In R.G. Van Driesche, T.S. Bellows Jr. (Eds.), *Biological Control* (pp. 3–18). New York: Chapman and Hall.
- Verma, M., Brar, S.K., Tyagi, R.D., Surampalli, R.Y., & Valero, J.R. (2007). Antagonistic fungi, *Trichoderma* spp.: panoply of biological control. *Biochemical Engineering Journal*, 37: 1–20.
- Verhey, W. (2010). Growth and Production of Rubber. In W. Verhey (Ed.), *Land Use, Land Cover and Soil Sciences*. Oxford: Encyclopedia of Life Support Systems (EOLSS), UNESCO-EOLSS Publishers.
- Vey, A., Hoagland, R.E., & Butt, T.M. (2001). Toxic Metabolites of Fungal Biocontrol Agents. In T.M. Butt, C.W. Jackson, N. Magan (Eds.), *Fungi as Biocontrol Agents: Progress, Problems and Potential* (pp. 311–346). Bristol: CAB International.

- Vinale, F., Sivasithamparam, K., Ghisalberti, E.L., Marra, R., Barbetti, M.J., Li, H., et al. (2008). A novel role for *Trichoderma* secondary metabolites in the interactions with plants. *Physiological and Molecular Plant Pathology*, 72: 80–86.
- Vinale, F., Sivasithamparam, K., Ghisalberti, E.L., Marra, R., Woo, S.L., & Lorito, M. (2008). *Trichoderma* plant pathogen interactions. *Soil Biology and Biochemistry*, 40: 1–10.
- Viterbo, A., Inbar, J., Hadar, Y., & Chet, I. (2007). Plant Disease Biocontrol and Induced Resistance via Fungal Mycoparasites. In C.P. Kubicek, I.S. Druzhinina (Eds.), *Environmental and Microbial Relationships, 2nd Edition The Mycota IV* (pp. 127–146). Berlin Heidelberg: Springer-Verlag.
- Vimaladevi, S., & Halangoda, L. (1971). Sulphur in the control of white root disease. *Quarterly Journal Rubber Research Institute of Ceylon*, 48, 82–91.
- Waghunde, R.R., Shelake, R.M., & Sabalpara, A.N. (2016). *Trichoderma*: A significant fungus for agriculture and environment. *African Journal of Agricultural Research*, 11(22): 1952–1965.
- Wang, R., Zhang, H-C., Sun, L-G., Qi, G-F., Chen, S., & Zhao, X-Y. (2017). Microbial community composition is related to soil biological and chemical properties and bacterial wilt outbreak. *Scientific Reports*, 7(343). Doi: [10.1038/s41598-017-00472-6](https://doi.org/10.1038/s41598-017-00472-6)
- Wardle, D.A., Bardgett, R.D., Klironomos, J.N., Setälä, H., van de Putten, W.H., & Wall, D.H. (2004). Ecological linkages between aboveground and belowground biota. *Science*, 304: 1629–1633.
- Wattanasilakorn, S. (2016). *Selection of Rubber (Hevea brasiliensis Muell. Arg.) Rootstocks for the White Root Disease Tolerance*. (Unpublished Ph.D. Thesis). Prince of Songkla University, Thailand.
- Wattanasilakorn, S., Sdoodee, S., Nualsri, C., & Chuenchit, S. (2012). Screening of rubber (*Hevea brasiliensis* Muell. Arg.) rootstocks for the white root disease resistance. *Journal of Agriculture Technology*, 8: 2385–2395.
- Weitzman, I., & Crist, M.Y. (1979). Studies with clinical isolates of *Cunninghamella*. I. Mating behavior. *Mycologia*, 71: 1024–1033.
- Weitzman, I., & Crist, M.Y. (1980). Studies with clinical isolates of *Cunninghamella*. II. Physiological and morphological studies. *Mycologia*, 72: 661–669.

- White, T.J., Bruns, T.D., Lee, S., & Taylor, J.W. (1990). Amplification and Direct Sequencing of Fungal Ribosomal RNA Genes for Phylogenetics. In M.A. Innis, D.H. Gelfand, J.S. Sninsky (Eds.), *PCR Protocols: A Guide to Methods and Applications*. New York: Academic Press.
- Widyastuti, S.M. (2006). The Biological Control of Ganoderma Root Rot by *Trichoderma*. In K. Potter, A. Rimbawanto, C. Beadle (Eds.), *Heart Rot and Root Rot in Tropical Acacia Plantations* (pp. 67–74). ACIAR Proceedings No. 124, Australian Centre for International Research, Canberra.
- Wijesundera, R.L.C., Jeganathan, S., & Liyanage, N.S. (1991). Some effects of isolates of *Trichoderma* on *Rigidoporus lignosus*. *Journal of Rubber Research Institute of Sri Lanka*, 2: 42–47.
- Wong, C.C. (1991). Personal communications, Karak.
- Yildiz, A., Benlioglu, K., & Benlioglu, H.S. (2014). First report of strawberry dieback caused by *Lasiodiplodia theobromae*. *Plant Disease*, 98(11): 1579.
- Yu, J., Walther, G., Diepeningen, A.D.V., Gerrits Van Den Ende, A.H.G., Li, R-Y., Moussa, A.A., Almaghrabi, O.A., & De Hong, G.S. (2015). DNA barcoding of clinically relevant *Cunninghamella* species. *Medical Mycology*, 53(2): 99–106.
- Yuliar Abidin, Z., & Mangunwardoyo, W. (2011). Potency of biocontrol agents isolated from compost and peat soil of tropical peat swamp forest in Kalamangan zone, central Kalimantan. *Journal of Forest Research*, 8: 144–157.
- Zahari, R., Halimoon, N., Sajap, A.S., Ahmad, M.F., & Mohamed, M.R. (2014). Bioantifungal activity of selected medicinal plant extracts against root rot of fungal disease. *Journal of Plant Sciences*, 2(1): 31–36.
- Zaini, H.M., & Halimoon, N. (2013). Stems extract of kemuning cina (*Catharanthus roseus*) as biofungicides against white root fungal (*Rigidoporus microporus*) of rubber trees (*Hevea brasiliensis*). *Journal of Biofertilizers & Biopesticides*, 4(2): id.136. Doi: [10.4172/2155-6202.1000136](https://doi.org/10.4172/2155-6202.1000136)
- Zakaria, M.H. (1989). *Some Aspects of the Biology and Chemically Assisted Biological Control of Ganoderma Species in Malaysia*. (Ph.D. Thesis). Universiti Putra Malaysia, Malaysia.
- Zapata, Y-M., Galviz-Quezada, A., Osorio-Echeverri, V-M. (2018). Cellulases production on paper and sawdust using native *Trichoderma asperellum*. *Universitas Scientiarum*, 23(3): 419–436.

Zehra, A., Dubey, M.K., Meena, M., & Upadhyay, R.S. (2017). Effect of different environmental conditions on growth and sporulation of some *Trichoderma* species. *Journal of Environmental Biology*, 38: 197–203.

Zhang, S., Xua, B., Zhang, J., & Gan, Y. (2018). Identification of the antifungal activity of *Trichoderma longibrachiatum* T6 and assessment of bioactive substances in controlling phytopathogens. *Pesticide Biochemistry and Physiology*, 147: 59–66.

