



UNIVERSITI PUTRA MALAYSIA

***MORPHOLOGICAL, MOLECULAR AND PATHOLOGICAL VARIABILITY
OF *Phytophthora* spp. FROM PERENNIAL CROPS IN MALAYSIA***

LATIFAH MUSANIF

FP 2017 63



**MORPHOLOGICAL, MOLECULAR AND PATHOLOGICAL VARIABILITY
OF *Phytophthora* spp. FROM PERENNIAL CROPS IN MALAYSIA**

By

LATIFAH BINTI MUSANIF

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

December 2016

COPYRIGHT

All materials contained within the thesis, including without limitation text, logos, icons, photographs and all other artwork, is copyright materials 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



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Master of Science

**MORPHOLOGICAL, MOLECULAR, AND PATHOLOGICAL VARIABILITY
OF *Phytophthora* spp. FROM PERENNIAL CROPS IN MALAYSIA**

By

LATIFAH BINTI MUSANIF

December 2016

Chairman : Nusaibah Binti Syd Ali, PhD
Faculty : Agriculture

Phytophthora causes various types of devastating diseases in different types of plants including annual and perennial crops, ornamental and forest trees in the tropical, subtropical, and temperate climates. In the tropics, *Phytophthora* spp. is considered as one of the most destructive pathogens of cocoa, rubber, durian and other commodity crops. However, the potential of *Phytophthora* spp. to cross-infect susceptible non-host plants were not extensively studied. *Phytophthora* spp. cross-infection studies are particularly important in intercropping systems practiced in plantations. Hence, the purpose of this study was to isolate, characterize and identify *Phytophthora* spp. from major perennial crops in Malaysia. In addition, pathogenicity and cross-pathogenicity of *Phytophthora* spp. between hosts and non-hosts such as oil palm were also studied. Identification of *Phytophthora* spp. was done through morphological, cultural and molecular characterizations based on Internal Transcribed Spacer (ITS) regions of ribosomal deoxyribonucleic acid (rDNA). Pathogenicity tests were carried out to confirm its pathogenicity towards its native host. Cross-pathogenicity tests were conducted to determine the potential of *Phytophthora* spp. in infecting susceptible non-hosts. Morphological characterizations of the isolated *Phytophthora* spp. indicated that most isolates from cocoa and durian formed striate and stellate colonies while isolates from rubber exhibited fluffy colonies on cornmeal agar (CMA), carrot agar and vegetable juice agar (V8). Optimum mycelial growth for all isolates was $28 \pm 1.5^{\circ}\text{C}$. In addition, sporangia from cocoa and durian were caducous with length to breadth ratios ranging from 1.51 to 1.69 and possessed short occluded pedicels. However, *Phytophthora* isolates from rubber displayed non-caducous sporangia with length to breadth ratios of 1.3 to 1.38. Nonetheless, all isolates were observed to produce abundant chlamydospores after two weeks of incubation. Therefore, in the present

study, 18 isolates of *Phytophthora* spp. were successfully isolated from cocoa, durian and rubber; 12 isolates from cocoa and durian were identified as *P. palmivora*, while six isolates were from rubber, *Phytophthora nicotianae* (synonym *P. parasitica*). Molecular identifications supported morphological and cultural characterizations of the isolated *Phytophthora* spp. *In-vitro* pathogenicity tests of 18 isolates on detached leaves and unripe cocoa pods exhibited the progressive development of lesions on its native host. Moreover, lesions were also developed in all wounded detached leaves and unripe cocoa pods regardless of hosts and isolates in cross-pathogenicity tests. However, there was a significant difference in the length of lesions developed, whereby longer lesions were detected on its native host compared to its non-native host. Additionally, inoculation of *Phytophthora* isolated from durian stem canker, cocoa pod rot, and rubber pod rot displayed infections on young immature oil palm leaflets by the development of discoloration. This discoloration developed after three days of incubation under moist conditions. Cross-inoculation studies also demonstrated that *Phytophthora* spp. was pathogenic to oil palm seedlings through the development of lesions on the buds. The pathogens were successfully re-isolated from the developed lesions of inoculated tissues, thus fulfilling Koch's postulates and this confirmed that *Phytophthora* spp. are pathogenic to oil palm. As conclusion, both conventional method (morphology and cultural studies), together with molecular identification confirmed that *Phytophthora* isolates from cocoa and durian were *P. palmivora*, whilst rubber isolates known as *P. nicotianae*. There was development of lesion on plant tissues regardless of host and non-host was noted, however more aggressiveness and length of lesion on own host in *in-vitro* test was observed. Both of *in-vitro* test and field trials also showed that *P. palmivora* and *P. nicotianae* in the present study were pathogenic to immature oil palm leaflets.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**MORFOLOGI, MOLEKULAR DAN KEPELBAGAIAN PATOLOGIKAL
Phytophthora spp. PADA TANAMAN SAKA DI MALAYSIA**

Oleh

LATIFAH BINTI MUSANIF

Disember 2016

Pengerusi : Nusaibah binti Syd Ali, PhD
Fakulti : Pertanian

Phytophthora menyebabkan pelbagai penyakit serius kepada banyak jenis tanaman sama ada tanaman saka, tanaman semusim, pokok-pokok hiasan serta pokok-pokok hutan di kawasan beriklim tropika, separa-tropika dan temperat. Di kawasan tropika, *Phytophthora* spp. dianggap sebagai salah satu patogen tumbuhan yang paling berbahaya pada pokok koko, getah, durian serta tanaman komoditi yang lain. Walaubagaimanapun, kajian mengenai potensi *Phytophthora* spp. untuk menjangkiti bukan perumah yang rentan masih tidak meluas. Kajian mengenai kebolehan *Phytophthora* spp. dalam jangkitan silang diantara perumah dan bukan-perumah adalah sangat penting dalam amalan pertanian campur yang diimplementasikan di ladang-ladang. Justeru itu, tujuan kajian ini dijalankan adalah untuk memencilkan, mencirikan serta mengenalpasti identiti *Phytophthora* spp. daripada tanaman saka yang utama di Malaysia. Tambahan pula, aras keagresifan serta potensi kepatogenan-silang *Phytophthora* spp. diantara perumah dan bukan perumah seperti pokok sawit juga menjadi salah satu objektif kajian ini. Pengecaman spesis *Phytophthora* telah dilakukan melalui ciri-ciri morfologi, kultura serta pencirian secara molekul berdasarkan kawasan "Internal Transcribed Spacer" (ITS) pada asid deoxyribonukleik di kawasan ribosom (rDNA). Ujian kepatogenan telah dijalankan bagi mengesahkan keagresifan pencilan *Phytophthora* terhadap perumahnya. Manakala ujian kepatogenan-silang dijalankan bagi menentukan kebolehan pencilan *Phytophthora* dalam menjangkiti bukan perumah yang rentan. Ciri-ciri morfologi pencilan daripada koko dan durian kebanyakannya mempunyai koloni "striate" dan "stellate", manakala pencilan daripada getah mempamerkan koloni yang gebu di atas media jagung (CMA), lobak, dan jus sayuran (V8). Suhu optimum pertumbuhan miselia bagi kesemua pencilan *Phytophthora* adalah $28 \pm 1.5^\circ\text{C}$. Selain itu, sporangia daripada pencilan koko dan durian adalah "caducous" (sporangia terpisah daripada sporangiofor) dengan nisbah panjang kepada lebar daripada 1.51 hingga 1.69 dan mempunyai pedisel yang pendek dan "occluded". Sebaliknya, pencilan daripada getah mempamerkan sporangia yang "non-caducous" dengan nisbah panjang kepada lebar daripada 1.30 hingga 1.38. Selain itu, kesemua pencilan didapati menghasilkan klamidospora dalam

kuantiti yang banyak selepas diinkubasi selama dua minggu. Oleh itu, dalam kajian ini, sebanyak 18 pencilan *Phytophthora* spp. telah berjaya dipencilkan daripada koko, durian dan getah; dimana 12 pencilan daripada koko dan durian telah diidentifikasi sebagai *P. palmivora* manakala enam lagi pencilan daripada getah, adalah *P. nicotianae* (sinonim dengan *P. parasitica*). Pencirian yang dilakukan secara molekul menyokong kaedah pencirian secara morfologi dan kultura terhadap pencilan-pencilan *Phytophthora*. Ujian kepatogenan secara *in-vitro* yang dijalankan terhadap 18 pencilan pada buah koko dan daun menunjukkan pencilan-pencilan tersebut berupaya menyebabkan lesi pada perumah asal dan bukan perumah asal. Walaubagaimanapun, kesan lesi adalah lebih panjang dan kritikal pada perumah asal berbanding dengan bukan perumah. Lesi juga terhasil apabila pencilan-pencilan *Phytophthora* diinokulasi ke atas pucuk muda kelapa sawit secara *in-vitro*. Pencilan-pencilan *Phytophthora* spp. daripada kesemua perumah terbukti patogenik pada anak sawit apabila berjaya menghasilkan lesi pada bahagian pucuk muda setelah diinokulasi secara buatan. Perubahan warna diperhatikan pada pucuk muda anak sawit selepas tiga hari diinkubasi dalam persekitaran yang lembap. Kedua-dua spesies *Phytophthora* telah berjaya dipencilkan kembali daripada kesan lesi pada anak-anak sawit akibat jangkitan dan ini memenuhi 'Koch postulate' serta mengesahkan *Phytophthora* spp. yang dikaji adalah patogenik terhadap anak sawit. Kesimpulannya, kedua-dua kaedah pencirian secara konvensional (pengkajian morfologi dan kultura) serta molekul telah mengesahkan pencilan-pencilan *Phytophthora* daripada koko dan durian adalah *P. palmivora* manakala pencilan-pencilan daripada getah dikenali sebagai *P. nicotianae*. Terjadi perkembangan lesi pada tisu perumah dan juga bukan perumah, akan tetapi lesi tersebut lebih agresif dan panjang saiznya pada tisu perumah dalam ujian *in-vitro* setelah diperhatikan. Kedua-dua, *P. palmivora* dan *P. nicotianae* dalam pengkajian ini adalah patogenik kepada tisu pucuk sawit belum matang berdasarkan pengkajian menerusi ujian *in-vitro* dan ujian lapangan.

ACKNOWLEDGEMENTS

In the name of Allah the Beneficent and Compassionate. Praise to almighty Allah S.W.T for His blessings who enabled me to complete this thesis and giving opportunity to pursue my master degree in Universiti Putra Malaysia (UPM).

I would like to express my deep gratefulness to my supervisor Dr. Nusaibah Binti Hj. Syed Ali, for her patient, guidance, invaluable advices and suggestions throughout the study period and completion of this thesis. Special thankful to my co-supervisor, Associate Professor Dr. Kamaruzaman Bin Sijam for his guidance, advices and generous help for value added this thesis.

My sincere appreciation is also extended to all staffs of Department of Plant Protection especially Mycology Laboratory and Molecular Laboratory staffs for their generous help and cooperation throughout my research.

Also, I would like to express my sincere appreciation to my colleagues and friends for their help and moral support. I am greatly thankful to the Government of Malaysia (My Brain-My Master) and Universiti Putra Malaysia for the Graduate Research Fellowship (GRF) for scholarship and financial support throughout my study period.

Finally, I gratefully acknowledged my beloved father, mother, brother and sisters for their moral encouragement, inspiration, patience, unfailing support and sacrifices. Thank you also to all those who are not mentioned here that help me to ensure the completion of my research.

I certify that a Thesis Examination Committee has met on 9 December 2016 to conduct the final examination of Latifah binti Musanif on her thesis entitled "Morphological, Molecular and Pathological Variability of *Phytophthora* spp. from Perennial Crops in Malaysia" 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 Master of Science.

Members of the Thesis Examination Committee were as follows:

Khairulmazmi bin Ahmad, PhD

Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Radziah binti Othman, PhD

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

Abdul Munir Abdul Murad, PhD

Associate Professor
Universiti Kebangsaan Malaysia
Malaysia
(External Examiner)



NØR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 26 January 2017

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

Nusaibah Syed Ali, PhD

Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Kamaruzaman Sijam, PhD

Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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 the 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, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti 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: Latifah Binti Musanif, GS34174

Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of the 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 of
Chairman of
Supervisory
Committee:

Dr. Nusaibah Syed Ali

Signature of
Member of
Supervisory
Committee:

Assoc. Prof. Dr. Kamaruzaman Sijam

TABLE OF CONTENTS

		Page
	ABSTRACT	i
	ABSTRAK	iii
	ACKNOWLEDGEMENT	v
	APPROVAL	vi
	DECLARATION	viii
	LIST OF TABLES	xiii
	LIST OF FIGURES	xiv
	LIST OF ABBREVIATIONS	xvii
 CHAPTER		
1	INTRODUCTION	1
2	LITERATURE RIVIEW	4
2.1	Taxonomy of <i>Phytophthora</i> genus	4
2.2	Epidemiology of <i>Phytophthora</i> disease	5
2.3	Life cycle of <i>Phytophthora</i> spp.	5
2.4	Host range	7
2.5	Pathogenesis of <i>Phytophthora</i>	7
2.6	Variability of <i>Phytophthora</i> spp.	9
2.6.1	Morphological characteristics	10
2.6.1.1	Sporangium	10
2.6.1.2	Chlamydo spores and hyphal swellings	13
2.6.1.3	Sexual structures	13
2.6.2	Molecular identification	14
2.7	<i>Phytophthora</i> disease in perennial crops	15
2.7.1	<i>Hevea brasiliensis</i> (Rubber)	15
2.7.2	<i>Durio zibethinus</i> (Durian)	17
2.7.3	<i>Theobroma cacao</i> (Cocoa)	19
2.7.4	<i>Elaeis guineensis</i> (Oil palm)	21
2.8	Epidemiology of bud rot disease	22
2.9	Oil palm bud rot disease management	23
2.10	<i>Phytophthora</i> disease management	23
3	ISOLATIONS, MORPHOLOGICAL AND MOLECULAR CHARACTERIZATION OF <i>Phytophthora</i> spp. ISOLATED FROM COCOA, DURIAN AND RUBBER	28
3.1	Introduction	28
3.2	Materials and Methods	29
3.2.1	Sample collection	29
3.2.2	Isolation of <i>Phytophthora</i> spp. from infected tissues	29
3.2.3	Colony morphology and growth rate	30
3.2.4	Temperature effects on growth	30
3.2.5	Spores characteristics	30

	3.2.5.1	Dimension and depth of apical thickening	30
	3.2.5.2	Caducity, pedicel length, width of exit-pore of sporangium	31
	3.2.5.3	Chlamydo spores production	31
	3.2.6	Experimental design and data analysis	31
3.3		Molecular identification of <i>Phytophthora</i> spp.	32
	3.3.1	Culture Preparation	32
	3.3.2	DNA extraction	32
	3.3.3	DNA qualitative analysis	33
	3.3.4	Amplification of ribosomal genomic DNA	33
	3.3.5	Electrophoresis	33
	3.3.6	Sequence analysis	33
3.4		Result	34
	3.4.1	Sample collection	34
	3.4.2	Isolation of <i>Phytophthora</i> spp.	37
	3.4.3	Identification of <i>Phytophthora</i> spp. based on morphological characters	39
	3.4.3.1	Colony morphology	39
	3.4.3.2	Growth rate on agar media	45
	3.4.3.3	Effect of temperature on mycelial growth	46
	3.4.3.4	Sporangium characteristics	47
	3.4.3.5	Chlamydo spores	54
3.5		Molecular characteristics results	56
3.6		Discussion	59
3.7		Conclusion	63
4		PATHOGENECITY AND CROSS-INFECTIVITY OF <i>Phytophthora</i> spp. AGAINST HOST AND POTENTIAL NON- HOST CROPS	64
	4.1	Introduction	64
	4.2	Materials and Methods	65
	4.2.1	Establishment of plants tissues	65
	4.2.2	Preparation of inoculum source	65
	4.2.3	Plants tissues inoculation	65
	4.2.3.1	Inoculation of excised durian and rubber leaves (Leaves assay)	65
	4.2.3.2	Inoculation of unripe cocoa pod	66
	4.2.3.3	Inoculation of excised immature oil palm leaflets	66
	4.2.4	Data collection	67
	4.2.5	Re-isolation	67
4.3		Cross-infectivity test (nursery trials) of oil palm seedlings	67
4.4		Results	68
	4.4.1	Pathogenicity and cross-infectivity test (<i>in-vitro</i> test)	68
	4.4.2	Cross infectivity test (nursery trials) of oil palm seedlings	76
4.5		Discussion	81
4.6		Conclusion	84

5	SUMMARY, GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH	85
	REFERENCES	88
	APPENDICES	110
	BIODATA OF STUDENT	129
	LIST OF PUBLICATIONS	130



LIST OF TABLES

Table	Page	
2.1	Classification of <i>Phytophthora</i> into six groups by Waterhouse (1963).	10
2.2	Avoidance strategies available to control oomycete diseases.	24
2.3	Exclusion strategies available to control oomycete diseases.	25
2.4	Strategies for protection against and therapy for <i>Phytophthora</i> and <i>Pythium</i> diseases.	26
2.5	Use of resistance to manage oomycete diseases caused by <i>Phytophthora</i> spp.	27
3.1	Source of <i>Phytophthora</i> spp. isolates from infected durian, rubber and cocoa.	34
3.2	Source of <i>Phytophthora</i> spp. isolates used in this study.	38
3.3	Colony growth rate (mm / day) of <i>Phytophthora</i> spp. isolates from cocoa, durian and rubber on four different types of media for seven days.	46
3.4	Means of mycelial linear growth of <i>Phytophthora</i> spp. isolates from cocoa, durian and rubber on corn meal agar at different temperatures after five days incubation.	47
3.5	Sporangial morphology of <i>Phytophthora</i> spp. from cocoa isolates after seven days of incubation in the light at 28±1.5 °C.	48
3.6	Sporangial morphology of <i>Phytophthora</i> spp. from durian isolates after seven days of incubation in the light at 28±1.5 °C.	50
3.7	Sporangial morphology of <i>Phytophthora</i> spp. from rubber isolates after seven days of incubation in the light at 28±1.5 °C.	52
3.8	Chlamydospores measurements of <i>Phytophthora</i> spp. isolated from cocoa, durian and rubber growing in V8 broth in the dark at 28±1.5 °C for 14 days.	55
3.9	Isolated and identified <i>Phytophthora</i> spp. associated with perennial crop diseases in Malaysia.	57
4.1	Mean lesion length developed on unripe cocoa pod inoculated with <i>Phytophthora</i> spp. after five days of incubation at 25±1.5 °C.	69
4.2	Mean lesion length on rubber leaves inoculated with <i>Phytophthora</i> spp. after three days incubation at 25±1.5 °C.	71
4.3	Mean lesion length on durian leaves inoculated with <i>Phytophthora</i> spp. after three days incubation at 25±1.5 °C.	73
4.4	Mean lesion length on immature oil palm leaflets inoculated with <i>Phytophthora</i> spp. after three days incubation at 25±1.5 °C.	76
4.5	Mean lesion length on oil palm seedling inoculated with <i>Phytophthora</i> spp. after five days inoculation (first trials).	78
4.6	Mean lesion length on oil palm seedling inoculated with <i>Phytophthora</i> spp. after five days inoculation (second trials).	79
4.7	Mean lesion length on oil palm seedling inoculated with <i>Phytophthora</i> spp. after five days inoculation (third trials).	79

LIST OF FIGURES

Figure		Page
2.1	Representative life cycle for <i>Phytophthora</i> spp.	6
2.2	<i>Phytophthora</i> infection cycle schematic diagram.	8
2.3	Sporangiophore morphology.	11
2.4	Morphology of <i>Phytophthora palmivora</i> (MF1 or S type). Lower row, globose oogonium with an amphigynous antheridium and an ovoid sporangium with a short pedicel. Upper row, variations in shapes of sporangia.	11
2.5	Morphology of <i>Phytophthora nicotianae</i> (= <i>P. parasitica</i>). Upper row, papillate, ovoid sporangia; germinating chlamydozoospores. Middle row, papillate, ovoid sporangia; germinating zoospores. Lower row, oogonia with amphigynous antheridia containing zoospores; terminal and intercalary chlamydozoospores.	12
2.6	Shapes of <i>Phytophthora nicotianae</i> (= <i>Phytophthora parasitica</i>) sporangia vary from ellipsoid, ovoid, pyriform, obpyriform, to spherical and not caducous. Papillate sporangia are produced singly or in a loose sympodium on long stalks.	12
2.7	Chlamydozoospores form at (A) terminal, (B) intercalary, (C) clustered form and (D) lateral location of hyphae/ mycelium.	13
2.8	Antheridial attachment – paragynous (A); amphigynous (B). Illustrations from Erwin and Ribeiro (1996).	14
2.9	Symptoms of black stripe disease, caused by <i>Phytophthora</i> on the tapping panel of a rubber tree (A). Dark-brown lesions on the petioles with one or two drops of coagulated latex in the centre of the lesion are a typical symptom of <i>Phytophthora</i> leaf fall (B); Symptoms of black stripe disease, caused by <i>Phytophthora</i> on the tapping panel of a rubber tree (C); Leaf blades from <i>Phytophthora</i> infected rubber trees (D).	16
2.10	Seedling blight of durian caused by <i>Phytophthora palmivora</i> (A); Lesion beneath the bark at the lower trunk of a durian tree. The lesioned tissue is brown compared to the creamy/pink colour of the healthy tissues (B). Durian fruit with large brown lesion caused by <i>Phytophthora palmivora</i> (C).	18
2.11	Seedling blight in the nursery (A); Stem canker, with the bark removed to show the underlying lesion (B); <i>Phytophthora</i> pod rot of cocoa (C).	19
2.12	Symptomatology of oil palm bud rot. Initial lesion on unopened leaflets (A); necrosis descending towards the meristematic zone (B); the spear leaf and next youngest leaves of this juvenile palm are exhibiting extensive necrosis due to a bud rot pathogen (C); the initial site of infection is on the unopened leaf blade of the spear leaf (D).	21
3.1	Symptoms of infected cocoa pod <i>Phytophthora</i> .; blackens, shrivels and the pod rot remained on the tree with the seeds inside shriveled and rotten (A). Symptom of <i>Phytophthora</i> pod rot was firm rot that can be distinguished from pod rot caused by	35

	<i>Botryodiplodia theobromae</i> and infections by <i>Colletotrichum</i> (B).	
3.2	Durian tree infected with stem canker disease lose its leaves (A). Initial symptom of canker; appearance of wet lesions on the bark (B). The tissues and wood appear dull discolored from cream to reddish brown when the bark was stripped away (C).	36
3.3	Green rubber pod infected by <i>Phytophthora</i> . Severe infection pods become black, malformed, unopened, with the seed inside shiveled and rotten.	37
3.4	Stellate and striate colonies of <i>Phytophthora palmivora</i> isolates from durian on vegetables juice agar (V8A) after seven days of incubation.	39
3.5	Stellate and striate colonies of <i>Phytophthora palmivora</i> isolates from durian on potato dextrose agar (PDA) after 14 days of incubation.	40
3.6	Stellate and striate colonies of <i>Phytophthora palmivora</i> isolates from durian on carrot agar (CA) after seven days of incubation.	40
3.7	Stellate and striate colonies of <i>Phytophthora palmivora</i> isolates from durian on corn meal agar (CMA) after seven days of incubation.	41
3.8	Rosaceous colonies of <i>Phytophthora palmivora</i> isolates from cocoa on vegetables juice agar (V8A) after seven days of incubation.	41
3.9	Stellate and striate colonies of <i>Phytophthora palmivora</i> isolates from cocoa on potato dextrose agar (PDA) after 14 days of incubation.	42
3.10	Stellate and striate colonies of <i>Phytophthora palmivora</i> isolates from cocoa on carrot agar (CA) after seven days of incubation.	42
3.11	Stellate and striate colonies of <i>Phytophthora palmivora</i> isolates from cocoa on corn meal agar (CMA) after seven days of incubation.	43
3.12	Fluffy colonies of <i>Phytophthora nicotianae</i> (synonyms <i>P. parasitica</i>) from rubber on vegetables juice agar (V8A) after seven days.	43
3.13	Colonies of <i>Phytophthora nicotianae</i> (synonyms <i>P. parasitica</i>) from rubber on potato dextrose agar (PDA) after seven days.	44
3.14	Colonies of <i>Phytophthora nicotianae</i> (synonyms <i>P. parasitica</i>) from rubber on carrot agar (CA) after seven days.	44
3.15	Colonies of <i>Phytophthora nicotianae</i> (synonyms <i>P. parasitica</i>) from rubber on corn meal agar (CMA) after seven days.	45
3.16	Ovoid-shaped sporangia identified as <i>Phytophthora palmivora</i> from cocoa isolates.	49
3.17	Sporangium of <i>Phytophthora</i> isolate from cocoa was caducous (sporangia that separate readily from sporangiophore) with prominent papilla and short pedicel.	49
3.18	Sporangium of <i>Phytophthora</i> isolate from durian was caducous (sporangia that separate readily from sporangiophore) with prominent papilla and short pedicel.	51
3.19	Ellipsoid-shaped sporangia identified as <i>Phytophthora palmivora</i> from durian isolates.	51

3.20	Sporangium of <i>Phytophthora</i> isolate from rubber with prominent papilla.	53
3.21	Ovoid and spherical shape of sporangia of <i>Phytophthora nicotianae</i> (synonyms <i>P. parasitica</i>) from rubber isolates.	53
3.22	Chlamydospores of <i>Phytophthora</i> from durian (A), cocoa (B) and rubber (C).	54
3.23	Amplified PCR products showing band approximately 800 bp to 900 bp on 1.5% agarose gel.	56
3.24	Amplified PCR products showing band approximately 900 bp on 1.5% agarose gel.	56
3.25	Phylogenetic tree derived from Neighbour-Joining method showing the genetic relationship among 18 isolates of <i>Phytophthora</i> spp. isolated from cocoa, durian and rubber.	58
4.1	Lesions progress on unripe cocoa pod after five days of inoculation with <i>Phytophthora</i> spp. at 25 ± 1.5 °C.	70
4.2	Lesions progress on rubber leaves after three days of inoculation with <i>Phytophthora</i> spp. at 25 ± 1.5 °C.	72
4.3	Lesions progress on excised durian leaves after three days of inoculation with <i>Phytophthora</i> spp. at 25 ± 1.5 °C.	74
4.4	Lesions progress on excised immature oil palm leaflets after three days of inoculation with <i>Phytophthora</i> spp. at 25 ± 1.5 °C.	75
4.5	Lesion development on bud of oil palm seedlings. A: Bud of healthy oil palm seedling (uninoculated); B: Bud of oil palm seedling infected with R3A (rubber isolate); C: Bud of oil palm seedling infected with DSCB4 (durian isolate); D: Bud of oil palm seedling infected with CPR244 (cocoa isolate).	77
4.6	Re-isolation of pathogen on corn meal agar (CMA). (A, B, C): inoculated with <i>Phytophthora nicotianae</i> (R3A); (D, E, F): inoculated with <i>Phytophthora palmivora</i> (DCSB4); (G, H, I): inoculated with <i>Phytophthora palmivora</i> (CPR244).	80

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
BLAST	Basic Local Alignment Search Tool
bp	base pair
CA	Carrot agar
CMA	Cornmeal agar
CRD	Complete Randomized Design
CTAB	N-Cetyl-N,N,N-Trimethyl-ammonium bromide
°C	Degree Celsius
ddH ₂ O	double distilled water
DNA	Deoxyribonucleic acid
EDTA	Ethylenediamine tetra acetic acid
g	Gram
ITS	Internal Transcribed Spacer
L	Liter
MEGA	Molecular Evolutionary Genetics Analysis
M	Molar
mL	Milliliter
mg	Milligram
min	Minute
NaOH	Sodium hydroxide
NCBI	National Center for Biotechnology Information
PCNB	Pentachloronitrobenzene
PCR	Polymerase Chain Reaction
PDA	Potato Dextrose Agar
%	Percent
rpm	rotation per minute
rDNA	ribosomal Deoxyribonucleic acid
TAE	Tris-acetate EDTA
Tris	Tris (hydroxymethyl) aminomethane
µg	Microgram
µL	Microliter
V8A	Vegetables Juice Agar
V	Voltage
w/w	weight per weight

CHAPTER 1

INTRODUCTION

Phytophthora means ‘plant destroyer’ in Greek; is a plant pathogen causing various devastating diseases in different types of plants including annual and perennial crops. Some *Phytophthora* spp. infect only one or two species of host plants though most cause diseases on many types of host plants (Agrios, 2005). *Phytophthora* spp. infection occurs in all life stages of forest trees including roots and crowns causing trunk cankers to foliar blights with a huge impact on forest ecosystems (Erwin and Ribeiro, 1996). It is a flexible and very effective pathogen due to its uncommon genetic architecture that enables *Phytophthora* to cause rapid evolution in pathogenicity (Jiang *et al.*, 2008; Raffaele *et al.*, 2010; Seidl *et al.*, 2011).

The importance of *Phytophthora* genus in plant pathology eventually started when *P. infestans* destroyed Ireland’s staple potato crops in 1845 and 1846, a time known as the Irish Potato Famine. The famine resulted in severe potato blights and it is estimated that Ireland lost one-fourth of its eight million inhabitants due to starvation and emigration (Bourke, 1991).

By the year 1996, there were 58 *Phytophthora* spp. that had been described by Erwin and Ribeiro (1996). Currently, the genus *Phytophthora* consists of more than 100 species and this continues to rise (Érsek and Ribeiro, 2010). Thus, there is no doubt that *Phytophthora* will be a continued global threat for decades to come.

To date, the threat still remains with a new wave of late blight epidemics in the 1990s due to the emergence of highly aggressive and fungicide-insensitive isolates in North America and Europe (Fry and Goodwin, 1997a, 1997b; Schiermeier, 2001; Smart and Fry, 2001). Although chemicals targeting the pathogen can provide some level of control, late blight is still a damaging disease particularly since the crops infected by *P. infestans* are grown in every state in the United States of America. As a result, crop losses and control measures are estimated to cost several billion dollars annually worldwide (Duncan, 1999; Schiermeier, 2001).

In another study, Rizzo *et al.* (2002) discovered *P. ramorum*, a new pathogenic species in oak trees in California and it was also found on several horticultural species, larch and Sitka spruce in Britain. Apart from that, *P. alni* was identified as the causal agent of lethal root and collar rot of the alder species in Europe (Brasier and Kirk, 2004).

Recently, Hee *et al.* (2013) reported that ‘Jarrah dieback’ caused by *P. cinnamomi* had caused the widespread decline of the dominant forest species of *Eucalyptus marginata* (jarrah). In Western Australia, *P. cinnamomi* is known as a biological bulldozer as 2284 of 5710 plant species are susceptible or highly susceptible (Shearer *et al.*, 2004).

In Southeast Asia (Thailand, Malaysia, Indonesia, Vietnam and Philippines) the economic impact of *Phytophthora* on cocoa, durian, rubber, coconut, pepper, citrus and potato was estimated to be at least US\$2.3 billion (Drenth and Sendall, 2004). Losses due to *Phytophthora* ranged from 5-10% for coconut and black pepper, to 15-25% for rubber, durian and cocoa (Drenth and Guest, 2004). Annual global losses due to *Phytophthora* spp. to the cocoa industry were estimated to be around 450 000 tonnes, valued at over US\$1 billion (Drenth and Guest, 2004; IPARC, 2012).

Rubber cultivation remained as an important element in the Malaysian economy instead of Malaysian 'golden crops'- oil palm. Malaysia is currently the world's fifth largest producer of natural rubber (NR) after Thailand, Indonesia, Vietnam and China. NR production in Malaysia increased by 4.1% from 0.67 million tonnes in 2014 to 0.72 million tonnes in 2015. Meanwhile, the exports of NR recorded a decline of 6.5% from 1.2 million tonnes in 2014 to 1.1 million tonnes in 2015. Nonetheless, Malaysia is still a net exporter of NR since Malaysia provide high-quality raw rubber with SMR (Standard Malaysian Rubber) grades. Malaysia produces speciality rubber such as ENR (Epoxidized Natural Rubber), DPNR (Deproteinized Natural Rubber), TPENR (Thermoplastic epoxidized natural rubber) and latex concentrates including Low Protein Latex (MREPC, 2016). In addition, Malaysia is globally renowned for its high-quality rubber product which currently exported to more than 190 countries globally. The value of exports of rubber products from Malaysia surpassed RM15 billion in 2014 and reached nearly RM18 billion in 2015 (MREPC, 2016).

Durian is a potential fruit to be commercialised since it is well received for its sweet and creamy flavour. It was consumed locally in Malaysia though a significant amount of good quality durians were exported to other countries. In 1991, Malaysia exported USD16.3 million worth of fresh durian, with about 90% to Singapore (Graef and Klotzbach, 1995). Recently, the durians are gaining in popularity among Chinese causing demand of frozen durian pulp enter China market (FAMA, 2014). The export value of Malaysian frozen durians to China had reached RM1.2 million in August last year, adding that the export value of the whole of last year was expected to surpass the RM1.6 million figure achieved in 2013 (News Straits Times, 2015). This potential profit value will be loss if *Phytophthora* disease did not manage effectively since *Phytophthora* spp. could infect at parts and at all growth stages of durian tree.

Cocoa is known as among primary commodity crops that planted in Malaysia after oil palm, rubber, kenaf and pepper. According to Department of Statistic Malaysia of Malaysian Cocoa Board (2016), the export value of cocoa industry was reached the amount of RM3.25 billion with 2809 tonnes cocoa beans production in 2013. However, the amount of cocoa beans production (upstream sector) still can't fulfil the demand of downstream sector cocoa product in Malaysia nowadays. Hence, the effort to increase the cocoa production through pest and disease management was the very important approach in order to reduce the amount of imported cocoa beans which needed cost more than RM2 billion annually.

Diseases caused by *Phytophthora* spp. are common in countries having tropical climates with high annual rainfall such as Malaysia. One of the most common species in the

tropics is *P. palmivora* which causes black pod in cocoa, root rot and blight of citrus, bud rot in palms, black stripe in rubber, stem canker, and fruit rot in durians (Drenth and Guest, 2004). The favourable environment enables the pathogen to cause disease throughout the year to susceptible host.

Phytophthora palmivora was identified as the causal agent of bud rot disease in oil palm in Columbia and its neighboring countries. It destroyed at least 45 000 hectares of oil palm estate causing significant economic losses (Martinez, 2009a; Torres *et al.*, 2010). The threat of the oil palm bud rot disease from South America hangs over the Malaysian oil palm industry as *P. palmivora* pathogenic to cocoa, durian, rubber and papaya are also present in Malaysia. However, reports of pathogenicity among hosts has not been extensively studied. In addition, no documented report of its pathogenicity on oil palm in Malaysia has been reported.

Thus, the specific objectives of this research were to isolate, characterize and identify *Phytophthora* spp. from major perennial crops in Malaysia, to determine its pathogenicity and cross-pathogenicity between hosts and to study its pathogenic potential on oil palm

REFERENCES

- Abad, G. (2008). Method for Identification of *Phytophthora* spp. In Fighting *Phytophthora*: How to detect, investigate and manage *Phytophthora*. Workshop, 26 July 2008, APS Centennial Meeting 2008.
- Agrios, G.N. (2005). *Plant Pathology* (5th edition). United Kingdom: Elsevier Academic Press.
- Ahmad Kamil, M.J. and Yahya, M.N. (1999). Screening epiphytic bacteria present on cocoa pods for antagonistic activities against *Phytophthora palmivora*, causal pathogen of black pod disease. Paper presented at MCB–MAPPS Plant Protection Conference 99, 2–3 November 1999, Kota Kinabalu, Sabah, Malaysia.
- Ahonsi, M.O., Banko, T.J. and Hong, C.X. (2007). A simple in vitro ‘wet plate’ method for mass production of *Phytophthora nicotianae* zoospores and factor influencing zoospore production. *Journal Microbiology Methods* 70:557 -560.
- Ahonsi, M.O., Banko, T.J., Doane, S.R., Demuren, A.O., Copes, W.E. and Hong, C.X. (2010). Effects of hydrostatic pressure, agitation and CO₂ stress on *Phytophthora nicotianae* zoospore survival. *Pest Management Science* 66: 696 –704.
- Alexopoulos, C.J., Mims, C.W. and Blackwell, M. (1996). *Introductory to Mycology*. John Wiley, New York.
- Ambikapathy, J., Marshall, J.S., Hocart, C.H., and Hardham, A.R. (2002). The role of proline in osmoregulation in *Phytophthora nicotianae*. *Fungal Genet Biol* 35: 287-299.
- Anderson, R.D. and Guest, D.I. (1990). The control of black pod, canker and seedling blight of cocoa, caused by *Phytophthora palmivora*, with potassium phosphonate. *Australasian Plant Pathology* 19: 127–129.
- Anon. (1986). RRIM planting recommendations 1986–8. *Planters Bulletin of Rubber Research Institute of Malaysia*, 186, 4– 22.
- Asare-Nyako, A. and Dakwa, J.T. (1974). The disease on roots. In *Phytophthora disease on cocoa*, ed. P.H. Gregory, pp.125-130. London: Logman.
- Ashby, S.F. (1929a). Strains and taxonomy of *Phytophthora palmivora* Butler (*P. faberi* Maubl.). *Transaction British Mycology Society* 14:18-38.
- Ashby, S.F. (1929b). Further note on the production of sexual organ in pure cultures of *Phytophthora cinnamomi* Rands. and *Blepharospora cambivora* Petri. *Transactions British Mycology Society* 14:260-263.
- Assinder, S.J. (2004). Molecular genetics and genomics of *Phytophthora*. *Applied Mycology & Biotechnology*, International series, Volume 4. Fungal Genomics, Elsevier, pp.139-143.
- Balajee, S.A. (2008). DNA sequence based method for species identification in the genus *Aspergillus*. In *Aspergillus in genomic era*, ed. J. Varga, and R.A. Samson, pp 261- 274, The Netherland: Wageningen Academic Publisher.

- Bartnicki-Garcia, S. and Wang, M.C. (1983). Biochemical aspects of morphogenesis in *Phytophthora*. In *Phytophthora: its biology, taxonomy, ecology and pathology*, ed. D. C. Erwin, S. Bartnicki-Garcia, and P.H. Tsao. St. Paul, Minnesota, USA: American Phytopathological Society.
- Batista, P.P., Santos, J.F., Oliveira, N.T., Pires, A.P.D., Motta, C.M.S., and Luna- Alves Lima, E.A. (2008). Genetic characterization of Brazilian strains of *Aspergillus flavus* using DNA markers. *Genetics and Molecular Research* 7 (3): 706-717.
- Beakes, G.W., Glockling, S.L. and Sekimoto, S. (2012). The evolutionary phylogeny of the oomycete 'fungi'. *Protoplasma* 249, 3–19.
- Belgrave, W.N.C. and Norris, F. de la M. (1917). Notes on bark cankers and their treatment, *Federated Malay States Agricultural Bulletin* 6: 2–10.
- Bennett, C.P., Roboth, O., Sitepu, G. and Lolong, A. (1986). Pathogenicity of *Phytophthora palmivora* (Butl.) causing premature nutfall disease of coconut (*Cocos nucifera* L.). *Indonesian Journal of Crop Science*, 2: 59–70.
- Benson, D. M. (1991). Detection of *Phytophthora cinnamomi* in azalea with commercial serological assay kits. *Plant Disease* 75:478–482.
- Bindslev, L., Oliver, R.P., and Johansen, B. (2002). In-situ PCR for detection and identification of fungal species. *Mycological Research*, 106(3):277-279.
- Blair, J.E., Coffey, M.D., Park, S.Y., Geiser, D.M., Kang, S. (2007). A multi-locus phylogeny for *Phytophthora* utilizing markers derived from complete genome sequences. *Fungal Genetics and Biology*, 45 (2008): 266-277.
- Boccas, B. R. (1973). Observations preliminaires sur l'heredite du pouvoir pathogene chez *Phytophthora palmivora* (Butl) Butl. Cah. *ORSTOM Ser. Biol.* 20:5 1- 56.
- Bong, C.L., and Stephen, M. (1999). In vitro assessment of sensitivity of cocoa clones to *Phytophthora* isolates. In: Sidek, Z., Bong, C.L., Vijaya, S.K., Ong, C.A. and Hussan, A.K., ed., Sustainable crop protection practices in the next millennium. MCB–MAPPS Plant Protection Conference 99, Kota Kinabalu, Sabah, Malaysia.
- Bong, C.L., Chong, T.C., Lim, K.L. and Lim, G.T. (1998). Experiences in cocoa clonal planting in Sabah, Malaysia with reference to crop protection. Paper presented at 3rd Malaysian International Cocoa Conference, 26–27 November 1998, Kuala Lumpur.
- Bong, C.L. (1993). Destructive diseases of selected fruit trees and species. In *Fruits, nuts and spices*, ed. W.W.W. Wong, and A. Lamb, pp.122–129. Proceedings of an in-house seminar and workshop, Lagud Sebrang, Tenom, Malaysia, 24–26 October 1990. Sabah, Malaysia: Department of Agriculture.
- Bourke, A. (1991). Potato blight in Europe in 1845. In *The scientific controversy of Phytophthora*, ed. J. Lucas, R.C. Shattock, D.S. Shaw, L.R. Cooke, pp. 12-24. Cambridge: Cambridge University Press.

- Bowman, K. D., Albrecht, U., Graham, J. H., and Bright, D. B. (2007). Detection of *Phytophthora nicotianae* and *P. palmivora* in citrus roots using PCR-RFLP in comparison with other methods. *European Journal Plant Pathology* 119:143-158.
- Brasier, C.M., and Graffin, M.J. (1979). Taxonomy of *Pytophthora palmivora* on cocoa. *Transactions British Mycology Society*, 72:111-143.
- Brasier, C.M. (1983). Problems and prospects in *Phytophthora* research. In *Phytophthora: its biology, taxonomy, ecology and pathology*, ed. D. C. Erwin, S. Bartnicki-Garcia, and P.H. Tsao. St. Paul, Minnesota, USA: American Phytopathological Society.
- Brasier, C.M. (1992). Evolutionary biology of *Phytophthora*: I. Genetic system, sexuality and the generation of variation. *Annual Review of Phytopathology* 30:153-171.
- Brasier, C.M., Cooke D.E.L. and Duncan, J.M. (1999). Proceeding National Academy Science USA 96:5878-5883: *Origin of a new Phytophthora pathogen through interspecific hybridization*. USA.
- Brasier, C.M. and Kirk, S.A. (2004). *Phytophthora alni*. *Mycological Research* 108: 1172–1184.
- Bruns, T. D., White, T. J., and Taylor, J. W. (1991). Fungal molecular systematics. *Annual Review Ecology Systemic* 22: 525–564.
- Bünemann, E.K., Schwenke, G.D. and Van Zwieten, L. (2006) Impact of agricultural inputs on soil organisms – a review. *Soil Research* 44, 379–406.
- Byrt, P.N., Irving, H.R., and Grant, B.R. (1982). The effect of organic compounds on the encystment, viability and germination of zoospores of *Phytophthora cinnamomi*. *Journal Genetic Microbiology* 128:1189-1198.
- Cahill, D.M. and Hardham, A.R. (1994). Exploitation of zoospore taxis in the development of a novel dipstick immunoassay for the specific detection of *Phytophthora cinnamomi*. *Phytopath* 84:193-200.
- Carlile, M.J. (1983). Motility, taxis and tropisms in *Phytophthora*. In *Phytophthora: its biology, taxonomy, ecology and pathology*, ed. D.C. Erwin, S. Bartnicki-Garcia, and P.H. Tsao, pp. 95–107. St Paul, Minnesota, USA: APS Press.
- Cecile, R., Carole, A. and Paolan, C. (2000). Relationship between biological control, incidence of hypovirulence and diversity of vegetative compatibility type of *Cryphonectria parasitica* in France. *Phytopathology* 90:730-737.
- Chambers, S.M., and Scott, E.S. 1995. In vitro antagonism of *Phytophthora cinnamomi* and *Phytophthora citricola* by isolates of *Trichoderma* spp. and *Gliocladium virens*. *Journal of Phytopathology* 143: 471–477.
- Chan, L.G. (1985). Comparative studies of *Phytophthora palmivora* from cocoa and durian and their control. Master Degree Thesis, Universiti Putra Malaysia.
- Chee, K.H. (1968). *Phytophthora* leaf disease in Malaysia. *Journal of Rubber Research Institute Malaya* 21: 79–86.

- Chee, K.H. and Wastie, R.L. (1970). Black Pod Disease of cocoa. *Planter Kuala Lumpur* 46:294-297.
- Chee, K.H. (1973). Production, germination and survival of chlamyospores of *Phytophthora palmivora* from *Hevea brasiliensis*. *Transactions British Mycological Society* 6:21-26.
- Cohen, Y. and Coffey, M.D. (1986) Systemic fungicides and the control of oomycetes. *Annual Review of Phytopathology* 24, 311–338.
- Colquhoun, I.J. and Kerp, N.L. (2007) Minimizing the spread of a soilborne plant pathogen during a largescale mining operation. *Restoration Ecology* 15, S85–S93.
- Colquhoun, I.J. and Hardy, G.E.St.J. (2000) Managing the risks of *Phytophthora* root and collar rot during bauxite mining in the *Eucalyptus marginata* (jarrah) forest of Western Australia. *Plant Disease* 84, 116–127.
- Coleman, A.W. and Vacquier, V.D. (2002). Exploring the phylogenetic utility of ITS sequences for animals: a test case for abalone (*Haliotis*). *Journal of Molecular Evolution* 54:246.257.
- Cobb, R.C., Meentemeyer, R.K. and Rizzo, D.M. (2010.) Apparent competition in canopy trees determined by pathogen transmission rather than susceptibility. *Ecology* 91, 327–333.
- Cook, A.A. (1975). *Diseases of tropical and subtropical fruit and nuts*. New York: Hafner Press.
- Cooke, D.E.L., Kennedy, D.M., Guy D.C., Russell, J., Unkles, S.E. and Duncan, J.M. (1996). Relatedness of group I species of *Phytophthora* as assessed by RAPDs and sequences of ribosomal DNA. *Mycological Research* 100: 297- 303.
- Cooke, D. E. L., and Duncan, J. M. (1997). Phylogenetic analysis of *Phytophthora* species based on the ITS1 and ITS2 sequences of ribosomal DNA. *Mycology Research* 101: 667–677.
- Cooke, D.E.L., Drenth, A., Duncan, J.M., Wagels, G., Brasier, C.M. (2000). A molecular phylogeny of *Phytophthora* and related Oomycetes. *Fungal Genetic Biology* 30: 17–32.
- Cooke, D.E.L., Duncan, J.M., Williams, N.A., Hagenaar-De Weerd, M. and Bonants, P.J.M. (2001). Identification of *Phytophthora* species on the basis of restriction enzyme fragment analysis of the Internal Transcribed Spacer regions of ribosomal RNA. *OEPP/EPPO Bulletin* 30: 519–523.
- Cooke, B.M. (2006). Disease Assessment and Yield Loss. In *The epidemiology of Plant Disease (2nd edition)*, ed. B.M. Cooke, D.G. Jones and B. Kaye, pp.43-80. The Netherlands: Springer.
- Cother, E.J. and Griffin, D.M. (1974). Chlamyospore germination in *Phytophthora drechsleri*. *Transactions of the British Mycological Society* 63:273–279.
- Crawford, A. R., Bassam, B. J., Drenth, A., MacLean, D. J. and Irwin, J. A. G. (1996). Evolutionary relationships among *Phytophthora* species deduced from rDNA sequence analysis. *Mycology Research* 100: 437–443.

- Darvas, J.M., Toerien, J.C. and Milne, D.L. (1984). Control of avocado root rot by trunk injection with fosetyl-Al. *Plant Disease*, 68:691–693.
- Dastur, J. F. 1913. *Phytophthora parasitica* n. sp., a new disease of the castor oil plant. Mem. Dep. Agric. India, Bot. Ser. 5 (4):177-231. In *Phytophthora Diseases Worldwide*, ed. D.C. Erwin and O. K. Ribeiro. St. Paul, Minnesota: APS Press.
- Davidson, J.M., Wickland, A.C., Patterson, H.A., Falk, K.R. and Rizzo, D.M. (2005) Transmission of *Phytophthora ramorum* in mixed-evergreen forest in California. *Phytopathology* 95, 587–596.
- Davidson, J.M., Patterson, H.A. and Rizzo, D.M. (2008) Sources of inoculum for *Phytophthora ramorum* in a redwood forest. *Phytopathology* 98, 860–866.
- Davis, F.W., Borchert, M., Meentemeyer, R.K., Flint, A. and Rizzo, D.M. (2010) Pre-impact forest composition and ongoing tree mortality associated with sudden oak death in the Big Sur region, California. *Forest Ecology and Management* 259, 2342–2354.
- Desjardins, P. R., Zentmeyer, G.A. and Reynolds, D.A. (1969). Electron microscopic observations of the flagellar hairs of *Phytophthora palmivora* zoospores. *Canadian Journal of Botany* 47:1077-1079.
- Dick, M.W. (2001). *Straminipilous Fungi*. Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Dobrowolski, M.P., Shearer, B.L., Colquhoun, I.J., O'Brien, P.A. and Hardy, G.E.St.J (2008) Selection for decreased sensitivity to phosphite in *Phytophthora cinnamomi* with prolonged use of fungicide. *Plant Pathology* 57, 928–936.
- Doohan, F. (2005). Fungal pathogens of plants. In *Fungal Biology and Applications*, ed. K. Kevin, pp 267. John Wiley & Sons, Ltd.
- Drenth, A. and Sendall, B. (2001). *Practical guide to detection and identification of Phytophthora* (version 1.0). CRC: Tropical Plant Protection. Brisbane, Australia.
- Drenth, A. and Guest, D.I. (2004) *Phytophthora* in the tropics. In *Diversity and Management of Phytophthora in Southeast Asia*, ed. A. Drenth, and D.I. Guest, pp. 30-41. Australian Centre for International Agricultural Research (ACIAR): Canberra.
- Drenth, A. and Sendall, B. (2004). Economic impact of *Phytophthora* diseases in Southeast Asia. In *Diversity and Management of Phytophthora in Southeast Asia*, ed. A. Drenth, and D.I. Guest, pp. 10–28;97-99. Australian Centre for International Agricultural Research (ACIAR): Canberra.
- Drenth, A. and Guest, D.I. (2013). *Phytophthora palmivora* in tropical tree crops. In *Phytophthora: A Global Perspective*, ed. K. Lamour, pp.190. CAB International.
- Drenth, A., Torres, G.A. and Martinez, G. (2013). Bud rot in oil palm. *Palmas* 34:87-94.
- Driver, F., Milner R.J. and Trueman, J.W.H. (2000). A taxonomic revision of *Metarhazium* based on a phylogenetic analysis of rDNA sequence data. *Mycological Research* 104: 134-150.

- D'Souza, N.K., Colquhoun, I.J., Shearer, B.L. and Hardy, G.E.St.J. (2004). The potential of five western Australian native *Acacia* species for biological control of *Phytophthora cinnamomi*. *Australian Journal of Botany* 52, 267–279.
- Duncan, J.M., Kennedy, D.M., and Scott P.H. (1991). Relationship between non-papillate soil-borne species of *Phytophthora*: Root rot of raspberry. In *Phytophthora*, ed. J.A. Lucas, R.C. Shattock, D.S. Shaw, and L.R. Cooke, pp. 129-147. Cambridge, United Kingdom: Cambridge University Press.
- Duncan, J. (1999). *Phytophthora*-an abiding threat to our crops. *Microbiology Today* 26:114-116.
- Edathil, T.T. and George, M.K. (1976). *Phytophthora necotianae* var. *parasitica* (Dastur) Waterhouse on *Hevea brasiliensis* in South India. *Rubber Board Bulletin* 13:3-4.
- El-Tarabily, K.A., Sykes, M.L., Kurtboke, I.D., Hardy, G.E.S., Barbosa, A.M. and Dekker, R.F.H. (1996). Synergistic effects of a cellulase-producing *Micromonospora* and an antibiotic-producing *Streptomyces violascens* on the suppression of *Phytophthora cinnamomi* root rot of *Banksia grandis*. *Canadian Journal of Botany* 74: 618–624.
- Ersek, T., Schoeltz J. E. and English, J. T. (1994). PCR amplification of species-specific DNA sequences can distinguish among *Phytophthora* species. *Application Environmental Microbiology* 60:2616–2621.
- Ersek, T. and Ribeiro, O.K. (2010). An annotated list of new *Phytophthora* species described post-1996 *Acta Phytopathologica et Entomologica Hungarica* 45: 251–266.
- Erwin, D.C. and Ribeiro, O.K. (1996). *Phytophthora* diseases worldwide. St. Paul, Minnesota: APS Press.
- Estrada-Garcia, M. T., Callow, J. A. and Green, J. R. (1990). Monoclonal antibodies to the adhesive cell coat secreted by *Pythium aphanidermatum* zoospores recognise 200 x 10³ M, glycoproteins stored within large peripheral vesicles. *Journal of Cell Science* 95, 199-206.
- Fagan, H.J. (1984). An assessment of pathological research on cocoa in Jamaica from 1950–1980 and current research priorities. *Tropical Pest Management* 30: 430–439.
- FAMA (Federal Agricultural Marketing Authority). (2016). Export of Frozen Durian Pulp to China. <http://www.fama.gov.my/en/pengeksporan-durian-sejuk-beku-ke-china#.WGRFGth97IU> (accessed 29 Dec.2016)
- Fang, J.G. and Tsao, P.H. (1995). Efficacy of *Penicillium funiculosum* as a biological control agent against *Phytophthora* root rots of azalea and citrus. *Phytopathology*, 85, 871–878
- Farr, D. F., Bill, G. F., Chamuris, G. P. and Rossman, A. Y. (1989). *Fungi on plants and plant products in the United States*. St. Paul, Minnesota: American Phytopathological Society Press.
- Fichtner, E.J., Lynch, S.C. and Rizzo, D.M. (2009) Survival, dispersal, and potential soil-mediated suppression of *Phytophthora ramorum* in a California redwood–tanoak forest. *Phytopathology* 99, 608–619.

- Föster, H., Oudemans, P. and Coffey, M. D. (1990). Mitochondrial and nuclear DNA diversity within six species of *Phytophthora*. *Experimental Mycology* 14:18–31.
- Förster, H., Learn, G., and Coffey, M. D. (1995). Towards a better understanding of the evolutionary history of species of the genus *Phytophthora* using isozymes, DNA RFLPs and ribosomal spacer sequences. In *Proceedings of the European Association for Potato Research Conference: Phytophthora infestans* 150, ed. L. J. Dowley, E. Bannon, L. R. Cooke, T. Keane, and E. O'Sullivan, pp. 42–54. Dublin: Boole Press.
- Föster, H., Cummings, M.P., Coffey, M.D. (2000). Phylogenetic relationship of *Phytophthora* spp. based on ribosomal ITS I DNA sequence analysis with emphasis on Waterhouse groups V and VI. *Mycology Research* 104: 1055-1061.
- Franqueville, H. de. (2003). *Oil palm bud rot in Latin America*. Experimental Agriculture Volume 39, pp. 225-240. Cambridge University Press.
- Frank, R., Braun, H.E., Ishida, K. and Suda, P. (1976) Persistent organic and inorganic pesticide residues in orchard soils and vineyards of southern Ontario. *Canadian Journal of Soil Science* 56, 463–484.
- Fry, W.E. and Goodwin, S.B. (1997a). Re-emergence of potato and tomato late blight in the United States. *Plant Disease* 81:1349-1357.
- Fry, W.E. and Goodwin, S.B. (1997b). Resurgence of the Irish potato famine fungus. *Bioscience* 47: 363-371.
- Gardes, M. and Bruns, T.D. (1993). ITS primers with enhanced specificity for basidiomycetes: application to the identification of mycorrhiza and rusts. *Molecular Ecology* 2: 113-118.
- Garbelotto, M., Harnik, T.Y. and Schmidt, D.J. (2009) Efficacy of phosphonic acid, metalaxyl-M and copper hydroxide against *Phytophthora ramorum* in vitro and in planta. *Plant Pathology* 58, 111–119.
- Garbelotto, M. and Schmidt, D. (2009) Phosphonate controls sudden oak death pathogen for up to 2 years. *California Agriculture* 63, 10–17.
- Goheen, E.M., Hansen, E.M., Kanaskie, A., McWilliams, M.G., Osterbauer, N., Sutton, W. and Rehms, L. (2004) An eradication strategy for *Phytophthora ramorum* in Oregon coastal forests. *Phytopathology* 94, S35.
- Gonzalez, I. L., Sylvester, J.E., Smith, T.F., Stambolian, D. and Schmickel, R.D. (1990). Ribosomal RNA gene sequences and hominoid phylogeny. *Molecular Biology and evolution* 7:203,219.
- Goodwin, P. H., Kirkpatrick, B. C. and Duniway, J. M. (1989). Cloned DNA probes for identification of *Phytophthora parasitica*. *Phytopathology* 79:716–721.
- Goodwin, P. H., Kirkpatrick, B. C. and Duniway, J. M. (1990). Identification of *Phytophthora citrophthora* with cloned DNA probes. *Application Environmental Microbiology* 56:669–674.

- Graef, J. and Klotzbach, T. (1995). World market for durian. RAP [Regional Agribusiness Project] Market Information Bulletin, No. 3, March 1995.
- Grant, B.R., Dunstan, R.H., Griffith, J.M., Niere, J.O. and Smillie, R.H. (1990) The mechanism of phosphonic (phosphorous) acid action in *Phytophthora*. *Australasian Plant Pathology* 19, 115.
- Gregory, P.H. and Maddison, A.C. (1981). *Epidemiology of Phytophthora on Cocoa in Nigeria. Phytopathological Paper* 25. Commonwealth Mycological Institute, Kew, Surrey, United Kingdom.
- Grünwald, N. J., Martin, F. N., Larsen, M. M., Sullivan Press, C. M., Coffey, M. D., Hansen, E. M., and Parke, J. L. (2011). *Phytophthora-ID.org: A sequence-based Phytophthora identification tool. Plant Disease* 95: 337-342.
- Guarro, J., Gene, J. and Stichigel Alberto, M. (1990). Developments in Fungal Taxonomy. *Clinical Microbiology Reviews* 12 (3):454-500.
- Gubler, F. and Hardhama, R. (1991). The fate of peripheral vesicles in zoospores of *Phytophthora cinnamomi* during infection of plants. In *Electron Microscopy of Plant Pathogens*, pp. 197-210. Edited by K. Mengden & D. E. Lesemann. London: Springer-Verlag.
- Guest, D.I. and Grant, B.R. (1991). The complex action of phosphonates in plants. *Biological Reviews* 66: 159–187.
- Guest, D.I., Anderson, R.D., Phillips, D.A., Foard, H.J., Worboys, S. and Middleton, R.M. (1994). Long-term control of *Phytophthora* diseases of cocoa using trunk-injected phosphonate. *Plant Pathology* 43: 479–492.
- Guest, D.I. (2007). Black Pod: Diverse Pathogens with a Global Impact on Cocoa Yield. *Phytopathology* 97:1650-1653.
- Gunderson, J.H., Elwood, H., Ingold, A., Kindle, K. and Sogin, M.L. (1987). Phylogenetic relationships between chlorophytes, chrysophytes, and oomycetes In *Proceedings of the National Academy of Sciences USA* 84:5823–5827.
- Hall, G. (1993). An integrated approach to the analysis of variation in *Phytophthora nicotianae* and a redescription of the species. *Mycology Research* 97:559-574.
- Hardy, G.E.St.J. and Sivasithamparam, K. (1991) Suppression of *Phytophthora* root rot by a composted Eucalyptus bark mix. *Australian Journal of Botany* 39, 153.
- Hardy, G.E.St.J. and Sivasithamparam, K. (2002) Phytosanitary considerations in species recovery programs. In: Sivasithamparam, K., Dixon, K.W. and Barrett, R.L. (eds) *Microorganisms in Plant Conservation and Biodiversity*. Kluwer Academic, Dordrecht, The Netherlands, pp. 337–367.
- Harnik, T.Y., Mejia-Chang, M., Lewis, J. and Garbelotto, M. (2004) Efficacy of heat-based treatments in eliminating the recovery of the sudden oak death pathogen (*Phytophthora ramorum*) from infected California bay laurel leaves. *HortScience* 39, 1677–1680.

- Hawksworth, D. L., Kirk P. M., Sutton B. C. and Pegler D. N. (1995). Ainsworth and Bisby's Dictionary of the Fungi (8th ed). Wallingford, UK: CAB International.
- Hayden, K.J., Hardy G.E. St, J. and Garbelotto, M. (2013). Oomycete Diseases. In *Infectious Forest Diseases*, ed. P. Gonthier and G. Nicolotti, pp. 523-524. CAB International.
- Heitefuss, R. (1989) Crop and Plant Protection: The Practical Foundations. Halsted Press, New York.
- Hee, W.Y, Pernelyn, S. Torreña, Leila, M., Blackman and Adrienna, R. H. (2013). *Phytophthora cinnamomi* in Australia. In *Phytophthora: A Global Perspective*. ed. K. Lamour, pp. 124. The Australian National University, Canberra, Australia. CAB International.
- Heller, W.E. and Theilerhedtrich, R. (1994). Antagonism of *Chaetomium globosum*, *Gliocladium virens* and *Trichoderma viride* to four soil-borne *Phytophthora* species. *Journal of Phytopathology* 141: 390–394.
- Henry, T., Iwen, P.C. and Hinrichs, S.H. (2000). Identification of *Aspergillus* species using internal transcribed spacer regions 1 and 2. *Journal of Clinical Mycology* 38: 1510-1515.
- Hansen, E.M., Goheen, D.J., Jules, E.S. and Ullian, B. (2000) Managing Port-Orford-cedar and the introduced pathogen *Phytophthora lateralis*. *Plant Disease* 84, 4–14.
- Hibbett, D.S. (1992). Ribosomal RNA and fungal systemic. *Transaction Mycology Society Japan* 33: 533-556.
- Hillis, D.M., and Dixon, M.T. (1991). Ribosomal DNA: molecular evolution and phylogenetic inference. *Queensland Review Biology* 66:411,453.
- Hillis, D. M., Moritz, C. and Mable, B. K. (1996). Molecular Systematics. Sunderland, Massachusetts: Sinauer Associate, Inc.
- Hinrikson, H.P., Hurst, S.F., Lott, T.J. and Warnock, D.W. (2005). Assessment of ribosomal large-subunit D1-D2, internal transcribed spacer 1, and internal transcribed spacer 2 regions as target for molecular identification of medically important *Aspergillus* species. *Journal of Clinical Microbiology* 43: 2092-2103.
- Hirst, J.M., Le Riche, H.H. and Bascomb, C.L. (1961) Copper accumulation in the soils of apple orchards near Wisbech. *Plant Pathology* 10, 105–108.
- Ho, H.H. (1990). Taiwan *Phytophthora*. *Botanical Bulletin Academica Sinica* 31: 89–106.
- Ho, H.H. (1992). Key to the species of *Phytophthora* in Taiwan. *Plant Pathology Bulletin* (Taiwan) 1:104-109.
- Hoitink, H.A.J., Vandoren, D.M. and Schmitthenner, A.F. (1977) Suppression of *Phytophthora cinnamomi* in a composted hardwood bark potting medium. *Phytopathology* 77, 561–565.
- Hoitink, H.A.J., Stone, A.G. and Han, D.Y. (1997) Suppression of plant diseases by composts. *HortScience* 32, 184–187.

- Holliday, P. (1980). *Fungus Disease of Tropical Crops*. pp 607. Cambridge, United Kingdom: Cambridge University Press.
- Horner I.J. and Hough E.G. (2014). Pathogenicity of four *Phytophthora* species on kauri: in vitro and glasshouse trials. A report confidential prepared for Auckland Council. Plant & Food Research data: Milestone.
- Howard, K., Colquhoun, I.J. and Hardy, G.E.St.J. (1998) The potential of copper sulphate to control *Phytophthora cinnamomi* during bauxite mining in Western Australia. *Australasian Plant Pathology* 27, 51–58.
- Hüberli, D., Hayden, K.J., Calver, M. and Garbelotto, M. (2012) Intraspecific variation in host susceptibility and climatic factors mediate epidemics of sudden oak death in western US forests. *Plant Pathology* 61, 579–592.
- Ili Liyana, M. Spike in durian exports to China. *News Straits Times Online*, October 4, 2015, <http://www.nst.com.my/news/2015/10/spike-durian-exports-china>.
- Inglis, P.W., and Tigano, M.S. (2006). Identification and taxonomy of some entomopathogenic *Paecilomyces* spp. (Ascomycota) isolates using rDNA–ITS sequences. *Genetics and Molecular Biology* 29: 132-136.
- Innis, M.A., Gelfand, D.H., Sninsky, J.J., and White, T.J. (1990). *PCR protocols: a guide to methods and applications*. New York: Academic Press, Inc.
- International Pesticide Application Research Consortium (IPARC). (2012). The world's worst cocoa problems. IPARC, Imperial College, Ascot, Berks, UK. Available at: www.dropdata.org/cocoa/cocoa_prob.htm#Phytophthora (accessed 4 October 2012).
- Irving, H.R. and Grant, B.R. (1984). The effect of calcium on zoospore differentiation in *Phytophthora cinnamomi*. *Journal Genetic Microbiology* 130: 1569-1576.
- Irving, H. R., Griffith, J. M. and Grant, B. R. (1984). Calcium efflux associated with encystment of *Phytophthora palmivora* zoospores. *Cell Calcium* 5: 487-500.
- Jackson, T.J., Burgess, T., Colquhoun, I.J. and Hardy, G.E.St.J. (2000) Action of the fungicide phosphite on *Eucalyptus marginata* inoculated with *Phytophthora cinnamomi*. *Plant Pathology* 49, 147–154.
- Jeffers, S.N. (2006). Recipes for Media Useful in the Culture and Identification of *Phytophthora* species. In Identifying Species of *Phytophthora*. *Plant Disease Reporter*.70:1038-1043.
- Jiang, R.H., Tripathy, S., Govers, F. and Tyler, B.M. (2008). RXLR effector reservoir in two *Phytophthora* species is dominated by a single rapidly evolving superfamily with more than 700 members. *Proceedings of the National Academy of Sciences of the United States of America* 105: 4874–4879.
- Johnston, A. (1989). Diseases and pests. In *Rubber*, ed. C.C. Webster, and W.J.I. Balkwil, pp.415-458. New York: Longman Scientific and Technical.
- Judelson, H.S, and Blanco, F.A. (2005). The spores of *Phytophthora*: weapon as plant destroyer. *Netherlands Review Microbiology* 3: 47-58.

- Kelly, M. and Meentemeyer, R.K. (2002) Landscape dynamics of the spread of sudden oak death. *Photogrammetric Engineering and Remote Sensing* 68, 1001–1009.
- Kendrick, B. (1992). *The fifth kingdom* (2nd), ed. Ontario, pp. 213 –220. Canada: Mycologue Publications.
- Kennedy, D.M. and J.M. Duncan. (1995). A papillate *Phytophthora* species with specificity to *Rubus*. *Mycological Research* 99:57-68.
- Kinal, J., Shearer, B.L. and Fairman, R.G. (1993) Dispersal of *Phytophthora cinnamomi* through lateritic soil by laterally flowing subsurface water. *Plant Disease* 77, 1085–1090.
- King, M., Reeve, W., van der Hoek, M.B., Williams, N., McComb, J., O'Brien, P.A. and Hardy, G.E.St.J. (2010) Defining the phosphite-regulated transcriptome of the plant pathogen *Phytophthora cinnamomi*. *Molecular Genetics and Genomics* 284, 425–435.
- Ko, W.H. (1978). Heterothallic *Phytophthora*: evidence for hormonal regulation of sexual reproduction. *Journal of General Microbiology* 107:15-18.
- Ko, W. and Chase, L. (1973). Aggregation of zoospores of *Phytophthora palmivora*. *Journal Genetic Microbiology* 78: 79-82.
- Konam, J.K. (1999). Integrated management of *Phytophthora palmivora* diseases of cocoa in Papua New Guinea. PhD thesis, School of Botany, University of Melbourne, Australia.
- Konam, J.K. and Guest, D.I. (2002). Leaf litter mulch reduces the survival of *Phytophthora palmivora* under cocoa trees in Papua New Guinea. *Australasian Plant Pathology* 31: 381–383.
- Konam, J. K.; Guest, D. I. (2004). Role of flying beetles (Coleoptera: Scolytidae and Nitidulae) in the spread of *Phytophthora* pod rot of cocoa in Papua New Guinea. *Australasian Plant Pathology* 33: 55–59.
- Latijnhouwers, M. and Govers, F. (2003). A *Phytophthora infestans* G-protein 13 subunit is involved in sporangia formation. (In press).
- Latijnhouwers, M., de Wit, P.J.G.M. and Govers, F. (2003) Oomycetes and fungi: similar weaponry to attack plants. *Trends in Microbiology* 11: 462–469.
- Laxalt, M.A., Latijnhouwers, M., van Hulst, M., and Govers, F. (2002). Differential expression of G protein ϵ and β subunit genes during development of *Phytophthora infestans*. *Fungal Genetic Biology* 36: 137-146.
- Lazarovits, G. (2001) Management of soil-borne plant pathogens with organic soil amendments: a disease control strategy salvaged from the past. *Canadian Journal of Plant Pathology* 23, 1–7.
- Le Bihan, B., Camporota, P., Soulas, M.L., Salerno, M.I. and Perrin, R. (1997) Evaluation of soil solar heating for control of damping-off fungi in two forest nurseries in France. *Biology and Fertility of Soils* 25, 189–195.

- Lee, B.S. and Varghese, G. (1974). Studies on the genus *Phytophthora* in Malaysia. Reproduction and sexuality. *Malaysia Agricultural Research* 3:137-149.
- Lee, B.S. Integrated control of *Phytophthora* stem canker in durian. In *Recent development in durian cultivation: proceedings of the durian seminar*, Ipoh, Perak Darul Ridzuan, Malaysia, 25 June, 1992, ed. M. Osman, Z. A. Mohamed, O. M. Shamsudin, Malaysian Agricultural Research and Development Institute, Kuala Lumpur, Malaysia pp.81–87. (1992).
- Lee, B. S., and Taylor, J. W. (1992). Phylogeny of five fungus-like protocistan *Phytophthora* species, inferred from the internal transcribed spacers of ribosomal DNA. *Journal of Molecular Evolution* 9: 636–653.
- Lee, B. S., White, T. J. and Taylor, J. W. (1993). Detection of *Phytophthora* species by oligonucleotide hybridization to amplified ribosomal DNA spacers. *Phytopathology* 83:177–181.
- Lee, B.S., Kosittrakun, M. and Vichitrananda, S. (1994). Pathology and disease control. In *Durian: fruit development, postharvest physiology, handling and marketing in ASEAN*, ed. S. Nanthachai, pp. 62-66. Kuala Lumpur, Malaysia, ASEAN Food Handling Bureau.
- Lee, B.S. and Lum, K.Y. (2004). *Phytophthora* Diseases in Malaysia. In *Diversity and Management of Phytophthora in Southeast Asia*, ed. Drenth, A. and Guest, D.I. ACIAR Monograph 114 :(4.1) 60-67pp.
- Lengeler, K.B., Davidson, R.C., D'Souza, C., Harashima, T., Shen, W.C., Wang, P., Pan, X., Waugh, M., and Heitman, J. (2000). Signal transduction cascades regulating fungal development and virulence. *Microbial Molecular Biology Review* 64: 746-785.
- Leonian, L.H. (1934). Identification of *Phytophthora* species. W. Va Univ. Agric. Exp. Stn.Bull.262 pp.36.
- Lim T.K. and Chan L.G. (1986). Fruit rot of durian caused by *Phytophthora palmivora*. *Pertanika* 9 (3): 269-276.
- Lim, T.K., and Chan, L.G. (1986). Parasitism of *Phytophthora palmivora* by *Gliocladium roseum*. *Journal of Plant Diseases and Protection* 93: 509–514
- Lim, T.K. (1990). *Durian diseases and disorders*. Kuala Lumpur, Malaysia: Tropical Press.
- Liu, P.S.W. (1977). Diseases caused by *Phytophthora* and *Pythium* in Sabah. *Malaysia Technical Bulletin* 3, pp.48.
- Ludowici, V.A., Zhang, W., Blackman, L.M., and Hardham A.R. (2013). *Phytophthora necotiana*. In *Phytophthora: A Global Perspective*, ed. K. Lamour, pp. 113. CAB International.
- Mabbett, T.H. (1986). The biology and application need of *Phytophthora* pod rot of cocoa. *Cocoa Growers Bulletin* 37: 24–33.
- Mac Donald, J. D., Stites, J. and Kabashima, J. (1990). Comparison of serological and culture plate methods for detection of *Phytophthora* species. *Plant Disease* 74:655–659.

- MacKenzie, D.R., Elliot, V.J., Kidney, B.A., King E.D., Royer M.H. and Theberge, R.L. (1983). Application of modern approaches to the study of the epidemiology disease caused by *Phytophthora*. In *Phytophthora: Its Biology, Taxonomy, Ecology and Pathology*, ed. D.C. Erwin, S. Barnticki-Garcia, and P.H. Tsao, pp. 3030-313. American Phytopathological Society, St Paul, Minnesota.
- Malaysia Rubber Board (MRB).2009. *Rubber plantation and processing technology*. Kuala Lumpur, Malaysia: Perpustakaan Negara Malaysia.
- Maloney, P.E., Lynch, S.C., Kane, S.F., Jensen, C.E. and Rizzo, D.M. (2005) Establishment of an emerging generalist pathogen in redwood forest communities. *Journal of Ecology* 93, 899–905.
- Manohara, D., Mulya, K., Purwantara, A., and Wahyuno, D. (2004). *Phytophthora capsici* on Black Pepper in Diversity and Management of *Phytophthora* in Southeast Asia Edited by André Drenth and David I. Guest ACIAR Monograph 114.
- Martin, F.N., Tooley, P.W. (2003). Phylogenetic relationship among *Phytophthora* species inferred from sequence analysis of the mitochondrially-encoded cytochrome oxidase I and II genes. *Mycologia* 95: 269-284.
- Martin, F.N. (2013). Molecular identification of *Phytophthora*. In *Phytophthora. A Global Perspective*, ed. K. Lamour, pp.19. United Kingdom: Cabi International.
- Martinez-Culebras, P.V., Abad-Campos, P., and Garcia-Jimenez, J. (2004). Molecular characterization and PCR detection of the melon pathogen *Acremonium Cucurbitacearum*. *European Journal of Plant Pathology* 110: 801-809.
- Martinez, G. Bud rot, Sudden wilt, Red ring and Lethal wilt in oil palm in America. In *International Workshop on Awareness, detection and control of oil palm devastating diseases*. Kuala Lumpur, Malaysia. November 6. (2009a).
- Martinez, G., Arango, M., Torres, G., Sarria, G., Velez, D., Rodriguez, J., Mestizo, Y.A., Aya, Norena, C., Varon, F., Drenth, A., and Guest, D. I. (2010). Advances in the research of the two most important diseases on oil palm in Colombia: Bud rot and lethal wilt. PIPOC 2011 (Agriculture, Biotechnology & Sustainability). pp. 473-480.
- Martinez, G., Valez, D. C., Norena, C. and Varon, F. (2013). Proceedings of 5th MPOB-IOPRI International Seminar: New alternatives for the evaluation of oil palm genotypes for their resistance to bud rot disease caused by *Phytophthora palmivora*.pp.315.
- Mitchell, H.J. and Hardham, A.R. (1999). Characterisation of the water expulsion vacuole in *Phytophthora nicotianae* zoospores. *Protoplasma* 206:118-130.
- Matsumoto, C., Kageyama, K., Suga, H., and Hyakumachi, M. (1999). Intraspecific DNA polymorphisms of *Pythium irregulare*. *Mycology Research* 104:1333–1341.
- Matsumoto, C., Kageyama, K., Suga, H., Hyakumachi, M. (2000). Phylogenetic relationships of *Pythium* species based on ITS and 5.8S sequences of the ribosomal DNA. *Mycoscience* 40:321–331.

- MCB (Malaysian Cocoa Board). (2016). Statistics Production of Cocoa Beans by Region, Import & Export of Cocoa Beans and Cocoa Products, <http://www.koko.gov.my/lkm/loader.cfm?page=industry/statistic.cfm> (accessed 29 December 2016).
- McCarren, K.L., Mc Comb, J.A., Shearer, B.L. and Hardy, G.E. St. J. (2005). The role of chlamydospores of *Phytophthora cinnamomi* – a review. *Australasian Plant Pathology* 34:333–338.
- McGregor, A.J. (1982). A small-scale screening technique for evaluating fungicides against *Phytophthora palmivora* pod rot of cocoa. *Annals of Applied Biology* 101: 25–31.
- McGregor, A.J. (1984). Comparison of cuprous oxide and metalaxyl with mixtures of these fungicides for the control of *Phytophthora* pod rot of cocoa. *Plant Pathology* 33: 81–87.
- Mchau, G.R.A. and Coffey, M.D. (1994a). Isozyme diversity in *Phytophthora palmivora*: Evidence for a Southeast Asia center of origin. *Mycology Research* 98:1035 – 1043.
- McMohan, P. and Purwantara, A. (2004). *Phytophthora* on cocoa. In *Diversity and management of Phytophthora in Southeast Asia*, ed. A. Drenth and D.I. Guest, ACIAR Monograph 114:104-115.
- Medeiros, A.G. (1976). Sporulation of *Phytophthora palmivora* (Butl.). In *relation to epidemiology and chemical control of cacao black pod disease*. Comissão Executiva do Plano da Lavoura Cacaueira (CEPLAC), Centro de Pesquisas do Cacao, Setor sudoeste, Campus do Inmet, Cruzeiro, Brasil.
- Meentemeyer, R., Rizzo, D., Mark, W. and Lotz, E. (2004) Mapping the risk of establishment and spread of sudden oak death in California. *Forest Ecology and Management* 200, 195–214.
- Mircetich, S.M., Zentmyer, G.A. and Kendrick, J.B. (1968). Physiology of germination of chlamydospores of *Phytophthora cinnamomi*. *Phytopathology* 58: 666–671.
- Mircetich, S. M., Browne, G. T., Krueger, W. and Schreader, W. (1985). *Phytophthora* species isolated from surface water irrigation sources in California. *Phytopathology* 75:1346–1347.
- Morris, P.F. and Gow, N.A.R. (1993). Mechanism of electrotaxis of zoospores of phytopathogenic fungi. *Phytopathology* 83: 877–882.
- Morris, B.M. and Gow, N.A.R. (1993). Mechanism of electrotaxis of zoospores of phytopathogenic fungi. *Phytopathology* 83: 877-882.
- Morris, B.M., Reid, B., and Gow, N.A.R. (1992). Electrotaxis of zoospores of *Phytophthora palmivora* at physiologically relevant field strengths. *Plant Cell Environmental* 15: 345–353.
- MREPC (Malaysian Rubber Export Promotion Council). (2016). <http://www.mrepc.com/industry/industry.php> (accessed 29 December 2016).

- Navaratnam, S.J. (1966). Patch canker of the durian tree. *Malaya Agricultural Journal* 45 (3): 291–294.
- Newhall, A.G. *Copper fungicides for the control of Phytophthora pod rot of cacao*. Paper presented at the Second International Conference on Cocoa, Salvador e Itabuna, Brazil. (1967).
- Newhook, F.J., and Jackson G.V. (1977). *Phytophthora palmivora* in cocoa plantation soils in the Solomon Islands. *Transactions of the British Mycological Society* 69:31-68.
- Newhook, F.J. (1978). *Phytophthora cinnamomi* in native forests of Australia and New Zealand: indigenous or introduced? In *Microbial ecology*, ed. M.W. Loutit, and J.A.R. Heidelberg, Germany: Springer-Verlag.
- Newhook, F.J., Waterhouse G.M., and Stamps D.J. (1978). Tubular key to the species of *Phytophthora* de Bary. *Mycological paper, Commonwealth Mycological Institute* 143:1-20.
- O'Donnell, K., and Cigelnik, E. (1997). Two divergent intragenomic rDNA ITS2 types within monophyletic lineage of the fungus *Fusarium* are nonorthologous. *Molecular Phylogenetic and Evolution* 7:103-116.
- O'Donnell, K., Nirenberg, H.I., Aoki, T., and Cigelnik, E. (2000). A multigene phylogeny of the *Gibberella Fujikuroi* species complex: detection of additional phylogenetically distinct species. *Mycoscience*, 41: 61-78.
- O'Gara, E., Guest, D.I., Vawdrey, L., Langdon, P., and Diczbalis, Y. (2004). *Phytophthora* Diseases of Durian, and Durian-Decline Syndrome in Northern Queensland, Australia. In *Diversity and Management of Phytophthora in Southeast Asia* Edited by André Drenth and David I. Guest ACIAR Monograph 114.
- O'Gara, E., Vawdrey, L., Martin, T., Sangchote, S., van Thanh, H., Binh, L.N. and Guest, D. (2004). Screening for Resistance to *Phytophthora*. In *Diversity and Management of Phytophthora in Southeast Asia* Edited by André Drenth and David I. Guest ACIAR Monograph 114.
- Othman, A. S., Samsiah, M.S., Ishak, Z. and Russman, N. (2008). Endophytic fungi in *Theobroma cacao* L. leaves (clones PBC123 and KKM22). *Malaysian Cocoa Journal* 4: 6-12.
- Oudemans, P., and Coffey M. D. (1991). A revised systematics of twelve papillate *Phytophthora* species based on isozyme analysis. *Mycology Research* 95:1025–1046.
- Parra, G. and Ristiano, J.B. (2001). Resistance to mefenoxam and metalaxyl among field isolates of *Phytophthora capsici* causing *Phytophthora* blight of bell pepper. *Plant Disease* 85: 1069–1075.
- Phillips, A.J.L., Alves, A., Corrie, A., and Luque, J. (2005). Two new species of *Botryosphaeria* with brown, 1-septate ascospores and *Dothiorella* anamorphs. *Mycologia* 97:513-529.
- Pietrzak, U. and McPhail, D.C. (2004) Copper accumulation, distribution and fractionation in vineyard soils of Victoria, Australia. *Geoderma* 122, 151–166.

- Pilbeam, R.A., Howard, K., Shearer, B.L. and Hardy, G.E.St.J. (2011) Phosphite stimulated histological responses of *Eucalyptus marginata* to infection by *Phytophthora cinnamomi*. *Trees - Structure and Function* 25, 1121–1131.
- Pongpisutta, R. and Sangchote, S. (2004). Morphological and Host Range Variability in *Phytophthora palmivora* from Durian in Thailand. In *Diversity and Management of Phytophthora in Southeast Asia*, ed. A. Drenth, and D.I. Guest, pp. 53-57. Australian Centre of International Agriculture Research (ACIAR).
- Quillec, J.L., Renard, J.L. and Ghesquire, H. (1984). *Phytophthora heveae* of coconut: role in bud rot and nutfall. *Oleagineux* 39: 477–485.
- Radford, S.A., Johnson, E.M., Leeming, J.P., and Miller, M.R. (1998). Molecular epidemiological study of *Aspergillus fumigatus* in a bone marrow transplantation unit by PCR amplification of ribosomal intergenic spacer sequences. *Journal of Clinical Microbiology* 36: 1294-1299.
- Raffaele, S. Farrer, R.A. and Cano, L.M. (2010). Genome evolution following host jumps in the Irish potato famine pathogen lineage. *Science* 330: 1540–1543.
- Ramana, K.V. and Eapen, S. J (2000). Nematode induced diseases of black pepper. In *Black pepper, (Piper nigrum)*, ed. P.N. Ravindran, pp.269-296, Medicinal and Aromatic Plants-Industrial Profiles: Harwood Academic Publisher.
- Ratana, S. (2004). *Phytophthora* Diseases of Rubber. In *Diversity and Management of Phytophthora in Southeast Asia* Edited by André, Drenth. and David, I. Guest, ACIAR Monograph 114 (printed version published in 2004).
- Reid, B., Morris, B., and Gow, N.A.R. (1995). Calcium-dependent genus-specific autoaggregation of zoospores of phytopathogenic fungi. *Experimental Mycology* 19: 202-213.
- Ribeiro, O.K. (1983). Physiology of asexual sporulation and spore germination in *Phytophthora*. In *Phytophthora Its Biology, Taxonomy, Ecology, and Pathology*, ed. D.C. Erwin, S. Bartnicki-Garcia, and P.H. Tsao, pp. 55–70. St. Paul Minnesota: APS Press.
- Ristaino, J. B., Michael, M., Carol, L. T. and Gregory, P. (1998). PCR Amplification of Ribosomal DNA for Species Identification in the Plant Pathogen Genus *Phytophthora*. *Applied Environmental Microbiology*. 64(3):948.
- Rizzo, D.M., Garbelotto, M. and Hansen, E.M. (2005) *Phytophthora ramorum*: integrative research and management of an emerging pathogen in California and Oregon forests. *Annual Review of Phytopathology* 43, 13.1–13.27.
- Rizzo, D.M., Garbelotto, M., Davidson, J.M., Slaughter, G.W. and Koike, S.T. (2002) *Phytophthora ramorum* as the cause of extensive mortality of *Quercus* spp. and *Lithocarpus densiflorus* in California. *Plant Disease* 86: 205–214.
- Runner, P.D. (1969). Diseases of *Hevea* rubber in Thailand, with particular reference to those associated with *Phytophthora* species. *Report of Rubber Research Centre Thailand* 2:69.

- Ruth, F., Alberto, A., Josefina, M., and Ana, I. (2009). Sequence variation of the internal transcribed spacer (ITS) region of ribosomal DNA in *Cerastoderma* species (Bivalvia: Cardiidae). *Journal of Molluscan Studies* 76 (1):77-86.
- Schiermeier, Q. (2001). Russia needs help to fend off potato famine, researchers warn. *Nature* 410:1011. Shepherd SJ, van west P, and Gow NAR (2003). Proteomic analysis of asexual development of *Phytophthora palmivora*. *Mycology Research* 107: 395-400.
- Schlick, A., Kuhls, K., Meyer, W., Lieckfeld, E., Borner, T. and Messner, K., (1994). Fingerprinting reveals gamma-ray induced mutations in fungal DNA, implications for the identification of patent strains of *Trichoderma harzianum*. *Current Genetics* 26: 74–8.
- Seidl, M.F., Van den Ackerveken, G., Govers, F. and Snel, B. (2011). A domain-centric analysis of oomycete plant pathogen genomes reveals unique protein organization. *Plant Physiology* 155:628–644.
- Shea, S.R., Gillen, K.J. and Kitt, R.J. (1978) Variation in sporangial production of *Phytophthora cinnamomi* Rands on jarrah (*Eucalyptus marginata* Sm) forest sites with different understorey compositions. *Australian Forest Research* 8, 219–226.
- Shearer, B.L. and Crane, C.E. (2011) Habitat suitability of soils from a topographic gradient across the Fitzgerald River National Park for invasion by *Phytophthora cinnamomi*. *Australasian Plant Pathology* 40, 168–179.
- Shearer, B.L., Dillon, M.J., Kinal, J. and Buehrig, R.M. (2010) Temporal and spatial soil inoculum dynamics following *Phytophthora cinnamomi* invasion of Banksia woodland and Eucalyptus marginata forest biomes of south-western Australia. *Australasian Plant Pathology* 39, 293-311.
- Shearer, B.L., Crane, C.E. and Cochrane, A. (2004). Quantification of the susceptibility of the native flora of the South-West Botanical Province, Western Australia, to *Phytophthora cinnamomi*. *Australian Journal of Botany* 52: 435–443.
- Shari Fuddin, S. (1999). In-vitro study on *Bacillus mycoides*, a rhizosphere bacterium as an antagonist to *Phytophthora nicotianae*. Paper presented at MCB–MAPPS Plant Protection Conference 99, 2–3 November 1999, Kota Kinabalu, Sabah, Malaysia.
- Singh, B.P., Saikia, R.L., Yadav, M., Singh, R., Chauhan, V.S., and Arora, D.K. (2006). Molecular characterization of *Fusarium oxysporum* f.sp.*ciceri* causing wilt of chickpea. *African Journal Biotechnology* 5 (6): 497-502.
- Slamet, A.R. (1991). Pathogenicity test of three isolates of *Phytophthora palmivora* on black pepper, coconut, cacao and vanilla. *Bulletin Komunikasi Penelitian rempah dan obat, Bagor, Indonesia* 6(1).
- Smart, C.D. and Fry, W.E. (2001). Invasions by the late blight pathogen: renewed sex and enhanced fitness. *Biological Invasions* 3: 235-243.

- Smillie, R., Grant, B.R. and Guest, D. (1989) The mode of action of phosphite: evidence for both direct and indirect modes of action on three *Phytophthora* spp. in plants. *Phytopathology* 79, 921–926.
- Sogin, M.L. and Silberman, J.D. (1998). Evolution of the protists and protistan parasites from the perspective of molecular systematics. *International Journal Parasitology* 128:11-20.
- Srinivasulu, B., Gautam, B., Sujatha, A., Kalpana, M., Vijaya Lakshmi, P., Pavani Rani, A. Chandran, B.S.R.S., Rama Krishna, Y. (2008). Bud rot disease of coconut. *Ambajipeta Technical Bulletin*: 1-14.
- Stamps, D.J., Waterhouse, G.M., Newhook, F.J., and Hall, G.S. (1990). Revised tabular key to the species of *Phytophthora*, *Institute of Mycology Paper* 162: Agricultural Bureau of International Mycology Institute.
- Suddaby, T., Alhussaen, K., Daniel, R. and Guest, D. (2008) Phosphonate alters the defence responses of *Lambertia* species challenged by *Phytophthora cinnamomi*. *Australian Journal of Botany* 56, 550–556.
- Suzui, T.J., Kueprakone, U., and Kamphangridthrong, T. (1979). *Phytophthora* spp. Isolated from some economic plants in Thailand. *Technical Bulletin Tropical Agricultural Research Center* 12: 32–41.
- Swain, S., Harnik, T., Mejia-Chang, M., Hayden, K., Bakx, W., Creque, J. and Garbelotto, M. (2006) Composting is an effective treatment option for sanitization of *Phytophthora ramorum*-infected plant material. *Journal of Applied Microbiology* 101, 815–827.
- Swiecki, T. and Bernhardt, E. (2002) Evaluation of stem water potential and other tree and stand variables as risk factors for *Phytophthora ramorum* canker development in coast live oak. In: Proceedings of the Fifth Symposium on Oak Woodlands: Oaks in California's Changing Landscape, 2001, October 22–25, San Diego, California. In: Standiford, R.B., McCreary, D., Purcell, K.L. (eds) General Technical Report PSWGTR-184, US Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California, pp. 787–798.
- Swiecki, T. and Bernhardt, E. (2006) Disease risk factors and disease progress in coast live oak and tanoak affected by *Phytophthora ramorum* canker (sudden oak death). In: Proceedings of the Sudden Oak Death Second Symposium: The State of Our Knowledge, January 18–21, 2005 Monterey, California. General Technical Report PSW-GTR-196, US Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California, pp. 383–411.
- Tai, L.H. (1970). Studies of *Phytophthora palmivora*, the causal organism of patch canker disease of durian, pp 7. Cawangan Perkembangan, Jabatan Pertanian, K. Lumpur.
- Tan A.M. (1979). *Phytophthora* disease of rubber in Peninsular Malaysia. *Planters Bulletin* 158:11-19.
- Tainter, F.H. and Baker, F.A. (1996). Principles of Forest Pathology. John Wiley, Hoboken, New Jersey.

- Tao, Y.H., Ho, H.H., Wu, Y.H. and He, Y.Q. (2011). *Phytophthora nicotianae* causing Dendrobium Blight in Yunnan Province, China. *International of Journal Plant Pathology* 2 (4):177-186.
- Taylor, R.J., Salas, B. and Secor, G.A. (2002). Sensitivity of North American isolates of *Phytophthora erythroseptica* and *Pythium ultimum* to mefenoxam (metalaxyl). *Plant Disease* 86: 797–802.
- Thankamma, L. (1974). *Phytophthora nicotianae* var. *nicotianae* on *Anacardium occidentale* in south India. *Plant Disease Reporter* 58(8):767-768.
- Thankamma, L. (1983). *Phytophthora* species on eight indigenous host species in south India and their pathogenicity on rubber. *Indian Phytopathology* 36 (1):17-23.
- Thompson, A. (1934). A disease of the durian tree. *Malayan Agriculture Journal* 22:367-371.
- Thompson, J. N. and Burdon, J.J. (1992). Gene-for-gene evolution between plants and parasites. *Nature* 360:121-125.
- Thrower, L.B. (1960). Observations on the diseases of cacao pods in Papua and New Guinea I. Fungi associated with mature pods. *Tropical Agriculture* 37: 111–120.
- Tollenaar, D. (1958). *Phytophthora palmivora* of cocoa and its control. *Netherlands Journal of Agricultural Science* 6: 24– 38.
- Tooley, P.W. and Browning, M. (2008) Survival of *Phytophthora ramorum* chlamydospores at high and low temperatures. In: Frankel, S.J., Kliejunas, J.T. and Palmieri, K.M. (eds) Proceedings of the Sudden Oak Death Third Science Symposium, March 5-9, 2007 Santa Rosa, California. General Technical Report PSWGTR-214, US Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California, pp. 475.
- Tooley, P.W., Browning, M. and Berner, D. (2008) Recovery of *Phytophthora ramorum* following exposure to temperature extremes. *Plant Disease* 92, 431–437.
- Tooley, P. W., Bunyard, B.A., Carras, M.M. and Hatziloukas, E. (1997). Development of PCR primers from internal transcribed spacer region 2 for detection of *Phytophthora* species infecting potatoes. *Applied Environmental Microbiology* 63:1467–1475.
- Torres, G.A., Sarria, G.A., Varon, F., Coffey, M.D., Elliot and Martinez, G. (2010). First report of bud rot caused by *Phytophthora palmivora* on African oil palm (*Elaeis guineensis*) in Colombia. *Plant Disease* 94(9):1163.
- Tsao, P.H. (1969). Proceedings of the First International Citrus Symposium, University of California at Riverside: *Studies on the saprophytic behavior of Phytophthora parasitica in soil*, ed. H.D. Chapman, pp. 1221–1230. March 16–26, 1968, University of California-Riverside, Riverside, California.
- Tsao, P.H. and Ocana, G. (1969). Selective isolation of species of *Phytophthora* from natural soils on an improved antibiotic medium. *Nature* 223:636-638.

- Tsao, P.H. and Tummakate, R. (1977). The identity of a *Phytophthora* spp from black pepper in Thailand. *Mycologia* 69: 631–637.
- Tucker, C.M. (1931). Taxonomy of the genus *Phytophthora* de Bary. Missouri Agriculture Experimental Station Research. *Bulletin* 153:208.
- Turner, P.D. and Asomaning, E.G.A. (1962). Root infection of *Theobroma cacao* L. by *Phytophthora palmivora*. *Tropical Agriculture Trinidad* 39:339-343.
- Tuset, J.J., Hinajeros, C., Buj, A., Molins, A. and Cebolla, C. (1992). *Myrothecium roridum* and *M. verrucaria* as potential antagonists of *Phytophthora* spp. of coconut. Paper read at coconut *Phytophthora* workshop held at Manado, Indonesia.
- Tyler, B.M. (2001). Genetics and genomics of the oomycete-host interface. *Trends Genetics* 17:611-614.
- Tyler, B.M. (2002). Molecular basis of recognition between *Phytophthora* pathogens and their hosts. *Annual Review Phytopathology* 40: 137-167.
- Valappil Ashokan, K. and Angadi, S.M. (2009). Phylogenetic utility of secondary structure of ribosomal ITS2 and Cytochrome oxidase subunit-I (COI) in sarcoptes isolates from different hosts. *The Internet Journal of Genomic and Proteomics* 4:1.
- Valachovic, Y., Lee, C., Marshall, J. and Scanlon, H. (2008) Wildland management of *Phytophthora ramorum* in northern California forests. In: Frankel, S.J., Kliejunas, J.T. and Palmieri, K.M. (eds) Proceedings of the Sudden Oak Death Third Science Symposium, March 5-9, 2007 Santa Rosa, California. General Technical Report PSW-GTR-214, US Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California, pp. 305–312.
- Valachovic, Y., Lee, C., Marshall, J. and Scanlon, H. (2010) Forest treatment strategies for *Phytophthora ramorum*. In: Frankel, S.J., Kliejunas, J.T. and Palmieri, K.M. (eds) Proceedings of the Sudden Oak Death Fourth Science Symposium, June 15-18, 2009, Santa Cruz, California. General Technical Report PSWGTR-229, US Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California, pp. 239–248.
- Van De Lande, H. L., and Zadoks, J.C. (1999). Spatial patterns of spear in oil palm plantations in Suriname. *Plant Pathology* 48 (2):189-201.
- van de Peer, Y., van der Auwera, G. and De Wachter, R. (1996). The evolution of stramenopiles and alveolates as derived by substitution rate calibration of small ribosomal subunit RNA. *Journal of Molecular Evolution* 42: 201-210.
- van West, P., Appiah, A.A., and Gow, N.A.R. (2003). Advances in research on root pathogenic oomycetes. *Physiology Molecular Plant Pathology*. 62:99-113.
- van West, P., Morris, B.M., Reid, B., Appiah, A.A., Osborne, M.C., Campbell, T.A., Shepherd, S.J., and Gow, N.A.R. (2002). Oomycete plant pathogens use electric fields to target roots. *Molecular Plant-Microbe Interact* 15: 790-798.

- Vogler, A.P., and DeSelle, R. (1994). Evolution and phylogenetic information content of the ITS-1 region in the tiger beetle *Cicindela dorsalis*. *Molecular Biology Evolution* 11:393-405.
- Volgmyr, H. (2003). Phylogenetic relationship of *Peronospora* and related genera based on nuclear ribosomal ITS sequences. *Mycological Research* 107(10): 1132- 1142.
- Wang, Y., Meng, Y., Zhang, M., Tong, X., Wang, Q., Sun, Y., Quan, J., Govers, F. and Shan, W. (2011). Infection of *Arabidopsis thaliana* by *Phytophthora parasitica* and identification of variation in host specificity. *Molecular Plant Pathology* 12: 187–201.
- Warburton, A.J. and Deacon, J.W. (1998). Transmembrane Ca²⁺ fluxes associated with zoospore encystment and cyst germination by the phytopathogen *Phytophthora parasitica*. *Fungal Genetic Biology* 25:54-62.
- Waterhouse, G.M. (1963). Key to the species of *Phytophthora* de Bary, *Mycological Papers* 92. Kew, Surrey, England: Commonwealth Mycological Institute.
- Waterhouse, G.M. (1970). The genus *Phytophthora* de Bary. *Mycological papers* 122. Kew, Surrey, England: Commonwealth Mycological Institute.
- Waterhouse, G.M. (1974). *Phytophthora palmivora* and some related species. In *Phytophthora* disease of cocoa, ed. P.H. Gregory, pp.51 -70. London: Longman.
- Waterhouse, G.M. (1974a). The genus *Phytophthora* de Bary. *Mycology Paper* 122:1-59. Kew, Surrey, England: Commonwealth Mycological Institute.
- Waterhouse, G.M. (1974b). *Phytophthora* disease of cocoa. In *Other Phytophthora species recorded in cocoa*, ed. P.H. Gregory, pp.71-79. London: Longman.
- Weste, G. (1983). Population dynamics and survival of *Phytophthora*. In *Phytophthora: its biology, taxonomy, ecology and pathology*, ed. D.C. Erwin, S. Bartnicki-Garcia and P.H. Tsao, pp. 139-147. The American Phytopathological Society: St. Paul, Minnesota.
- Wharton, A.L. (1974). Cushion infection. In *Phytophthora disease of cocoa*, ed. P.H. Gregory, pp.71-79. London: Logman.
- White, T. J., Bruns, T., Lee, S., and Taylor, J. (1990). Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In *PCR protocols: a guide to methods and applications*, ed. M. A. Innis, D. H. Gelfand, J. J. Sninsky and T. J. White, pp. 315-322. San Diego: Academic Press.
- Wilcox, W. F. (1989). Identity, virulence and isolation frequency of seven *Phytophthora* species causing root rot of raspberry in New York. *Phytopathology* 79:93–101.
- Wilcox, W.F., Scott, P.H., Hamm, P.B., Kennedy, D.M., Duncan, J.M., Brasier, C.M., and Hansen, E.M. (1993). Identify of species *Phytophthora* attacking raspberry in Europe and North America. *Mycology Research* 97:817-831.
- Wilkinson, C.J., Holmes, J.M., Dell, B., Tynan, K.M., McComb, J.A., Shearer, B.L., Colquhoun, I.J. and Hardy, G.E.St.J. (2001a) Effect of phosphite on in planta zoospore production of *Phytophthora cinnamomi*. *Plant Pathology* 50, 587–593.

Wilkinson, C.J., Holmes, J.M., Tynan, K.M., Colquhoun, I.J., McComb, J.A., Hardy, G.E.St.J. and Dell, B. (2001b) Ability of phosphite applied in a glasshouse trial to control *Phytophthora cinnamomi* in five plant species native to western Australia. *Australasian Plant Pathology* 30, 343–351.

You, M.P., Sivasithamparam, K. and Kurboke, D.J. (1996). Actinomycetes in organic mulch used in avocado plantations and their ability to suppress *Phytophthora cinnamomi*. *Biology and Fertility of Soils*, 22: 237–242.



PUBLICATIONS

Accepted Journal Article

Latifah, M., Zainal Abidin, M.A, Kamaruzaman, S., and Nusaibah, S.A. (2017). Cross-infectivity of oil palm by *Phytophthora* spp. isolated from perennial crops in Malaysia. Short Communication. *Forest Pathology Wiley Blackwell* :1- 6

Latifah, M., Zainal Abidin, M.A, Kamaruzaman, S., and Nusaibah, S.A. (2017). Identification of *Phytophthora* spp. from perennial crops in Malaysia, its pathogenicity, and cross-pathogenicity. *Sains Malaysiana. UKM Press*.

Conference / Proceedings

Latifah, M., Zainal Abidin, M.A, Kamaruzaman, S., and Nusaibah, S.A. (2016). Identification of *Phytophthora* spp. from perennial crops in Malaysia, its pathogenicity, and cross-pathogenicity against hosts and potential hosts. *International Agriculture Congress. Faculty Agriculture, Universiti Putra Malaysia*. Poster Presentation

Latifah, M., Zainal Abidin, M.A, Kamaruzaman, S., and Nusaibah, S.A. (2017). Jangkitan-Silang Pencilan *Phytophthora* spp. Daripada Tanaman Saka Berkatu di Malaysia Terhadap Anak Sawit. Forum Pertanian IPIMA 2017. Majlis Profesor Negara. Pembentang Poster.



UNIVERSITI PUTRA MALAYSIA

**STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND
COPYRIGHT**

ACADEMIC SESSION :

TITLE OF THESIS / PROJECT REPORT :

MORPHOLOGICAL, MOLECULAR AND PATHOLOGICAL VARIABILITY OF
Phytophthora spp. FROM PERENNIAL CROPS IN MALAYSIA

NAME OF STUDENT : LATIFAH BINTI MUSANIF

I acknowledge that the copyright and other intellectual property in the thesis/project belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that the thesis is classified as:

*Please tick (/)

CONFIDENTIAL (Contain confidential information under Official Secret Act 1972).

RESTRICTED (Contain restricted information as specified by the organization / institution where research was done).

OPEN ACCESS I agree that my thesis/project report to be published as hard copy or online open access.

This thesis submitted for:

PATENT Embargo from _____ until _____

(date)

(date)

Approved by:

(Signature of Student)

(Signature of Chairman of Supervisory Committee)

New IC No/Passport No.:

Name:

Date:

Date:

(Note:If the thesis is CONFIDENTIAL or RISTRICTED, please attach with the letter from the organization/institution with period and resions for confidentially or ristricted)

