UNIVERSITI PUTRA MALAYSIA

EFFECTS OF ENTOMOPATHOGENIC FUNGUS (Metarhizium anisopliate) ON THE TERMITE (Coptotermes curvignathus)

HOE PIK KHENG

FSPM 2010 3

EFFECTS OF ENTOMOPATHOGENIC FUNGUS (*Metarhizium anisopliae*) ON THE TERMITE *(Coptotermes curvignathus)*

By

HOE PIK KHENG

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

September 2010

© COPYRIGHT UPM

© COPYRIGHT UPM

Dedicated to

My grandma and my family

© COPYRIGHT UPM

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

EFFECTS OF ENTOMOPATHOGENIC FUNGI (*Metarhizium anisopliae*) ON THE TERMITE (*Coptotermes curvignathus*)

By

HOE PIK KHENG

September 2010

Chairman: Joseph Bong Choon Fah, Ph.D

Faculty: Agriculture and Food Sciences, Bintulu

Coptotermes curvignathus (BLATTODEA: Rhinotermitidae) is a major termite pest in the oil palm plantations on peat as it attacks the living tissues of the plants. Biological control using *Metarhizium anisopliae* in the peat area has potential for termite control due to its advantages such as environmental friendly and non-hazardous to human health compared to chemical measures. In this study, several isolates of *M. anisopliae* was obtained from both peat and mineral soils and screened for their pathogenic effect on *C. curvignathus*. Five potential isolates (TA, LR2, MG, CI and AR3) had been further characterised and evaluated for their pathogenicity activity and investigated for their mode of action. There was also no repellent effect of

© COPYRIGHT UPM

the termites towards the isolates. Among the five isolates isolate TA had the most potential, followed by isolate LR2 and the least potential was isolate CI. Isolate TA which was obtained from peat soil, had the highest virulence and exhibited the quickest sporulation at 2 days post inoculation. The ultra structural studies revealed that isolate TA was able to have a higher virulence level compared to other isolates was due to its quick germination and penetration (within 3 hours) of the mycelia into the termite body, where the colonization of mycelia happened subcutaneously. Between isolate TA and LR2, isolate TA that germinated and penetrated into the termite more quickly. Isolate CI was the least virulent as this was the only isolate that did not spread subcutaneously; hence, it was very likely that the mycelia would have been groomed off before they were able to penetrate. The total mortality of the termites was not only due to the infection of the isolates, but also due to the induced alarm behaviour by the isolates among the termites causing them to be buried or cannibalized the weakened or infected member. Direct applications, like drenching and topical application were very effective but not practical for field application, unless the termite nests or colony can be identified in the peat area. Hence, with a potential isolate like isolate TA and LR2, successful biological control for termites, *C. curvignathus*, for oil palms on peat can be achieved. However, enhancement of the potential isolates and a suitable application method can augment the effect of the isolates during the field applications.

© COPYRIGHT UPM

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

KESAN KULAT PATOGENIK SERANGGA (*Metarhizium anisopliae*) TERHADAP ANAI-ANAI (*Coptotermes curvignathus*)

Oleh

HOE PIK KHENG

September 2010

Pengerusi: Joseph Bong Choon Fah, Ph.D

Fakulti: Sains Pertanian dan Makanan, Bintulu

Coptotermes curvignathus (BLATTODEA: Rhinotermitidae) ialah perosak utama di ladang kelapa sawit di kawasan tanah gambut. Ini adalah kerana jenis anai-anai ini menyerang tisu-tisu hidup pada pokok kelapa sawit. Kawalan biologi dengan menggunakan *Metarhizium anisopliae* mempunyai potensi untuk kawalan anai-anai di kawasan tanah gambut. Ini adalah disebabkan oleh beberapa faedahnya seperti kesan baik kepada alam sekitar dan tidak berbahaya kepada kesihatan manusi jika dibandingkan kepada kawalan secara kimia. Dalam kajian ini, beberapa isolat *M. anisopliae* diperolehi daripada tanah gambut dan tanah mineral dan ditapis untuk kesan patogeniknya terhadap *C. curvignathus*. Lima isolat yang

© COPYRIGHT UPM

berpotensi (TA, LR2, MG, CI dan AR3) telah dikaji dan dinilai ciri-ciri dan kegiatan patogennya. Kaedah-kaedah tindakan lima isolat tersebut juga diselidik. Anai-anai tidak mempunyai aktiviti penolak terhadap kelima-lima isolat tersebut. Di antara lima isolat tersebut, isolat TA mempunyai paling potensi yang paling tinggi, diikuti oleh isolat LR2 dan isolat CI mempunyai potensi yang paling rendah Keputusan kajian ultra-struktur menunjukkan bahawa isolat TA memiliki kesan patogenik yang lebih tinggi jika dibandingkan dengan isolat-isolat yang lain kerana percambahan dan penembusan miselianya yang cepat (dalam masa 3 jam) ke dalam tubuh anai-anai, di mana kejadian penjajahan miselia lepas itu berlaku di bawah kulit anai-anai. Di antara isolat TA dan LR2, isolat TA yang bercambah dan menembusi ke dalam badan anai-anai dengan lebih cepat. Oleh kerana demikian, semakin lama isolat tersebut untuk menembus ke dalam badan anai-anai, kemungkinan konidia-konidia isolat untuk dibersihkan dari kulit anai-anai menjadi semakin. Isolat CI adalah isoalt yang paling tidak efektif kerana ia merupakan satu-satu isolat yang mempunyai miselia yang menjajah di atas kulit anai-anai. Oleh kerana demikian miselia tersebut mungkin akan dibersihkan oleh anai-anai yang lain sebelum miselia tersebut dapat menembus ke dalam badan anai-anai. Jumlah kematian anai-anai tidak semestinya disebabkan oleh jangkitan penyakit daripada isolat-isolat. Ia juga disebabkan oleh tingkah laku anai-anai yang disebabkan oleh isolat-isolat tersebut di mana anai-anai tersebut akan menanam dan menguburkan atau memakan ahli-ahli yang lemah atau dijangkiti penyakit. Kaedah applikasi secara langsung, seperti ‘drenching’ dan aplikasi topikal adalah sangat efektif tetapi ianya adalah tidak praktikal kecuali semburan dapat

© COPYRIGHT UPM

dilakukan pada sarang atau koloni jajahan anai-anai dapat dikenalpasti di kawasan tanah gambut. Oleh itu, dengan menggunkan satu isolat yang berpotensi seperti isolat TA dan LR2, kawalan biologi yang berjaya untuk anai-anai, *C. curvignathus*, pada tanaman kelapa sawit di kawasan tanah gambut boleh dicapai. Namun demikian, peningkatan potensi isolat tersebut dan kaedah applikasi yang sesuai untuk meningkatkan kesan isolat ketika penggunaannya dalam ladang

© COPYRIGHT UPM

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to all those who were directly or indirectly involved in the completion of this study.

My appreciation goes to my Supervisor Associate Professor Dr. Joseph Bong Choon Fah, for his sincere support, guidance and encouragement. My appreciation is also extended to Associate Professor Dr. Jugah Kadir who served as a member of my Advisory Committee and had helped me in arranging for the utilization of the Scanning Electron Microscope at the Faculty of Agriculture, UPM Serdang. Sincere appreciation is also extended to Associate Professor Dr. Rajan Amartalingam, who contributed a lot in shaping up my thesis.

My sincere appreciation also goes to Dr. Yiu Pang Hung and Mr. Wong Sie Chuong for allowing me to use of their lab and assisting me in the part of the molecular studies. I would also like to express my gratitude to Dr. Patricia King Jie Hung for her guidance in analyzing the molecular data.

I would like to thank Mr. Rafii from the Institute of Bioscience, UPM for their assistance in using the SEM. My sincere gratitude is also extended to Mr. Daud Mustam, Mr. Suhaimi Aman and Mr. Shamsudin Bojang from Faculty of Agriculture for their assistance in processing my electron microscopy samples. I would also like to thank Mrs. Siti Fatimah and Miss Siti Aziah from Department of Crop Sciences for their help in providing my experimental materials.

I would like to heartily thank my labmates from Pathology Lab, Mr. Chan Seow Phan, Mr. Lim Guan Miaw and Miss Wong Ling Chie for their tireless effort in aiding in my research for my thesis would never have materialized without them. Thanks are also extended to Miss Lee Huei Hong, Miss Phene Neoh and Miss Weng Bong for their guidance and assistance in the Molecular Laboratory. I would also like to thank Miss Lim Ya Li for her assistance in providing my materials during my research in UPM, Serdang.

I would like to thank the Ministry of Science, Technology and Innovation (MOSTI) for research funding and for providing scholarship. Without their support, I would not be able to conduct this research.

Finally and, above all, my family that deserves a lot of thanks and appreciations, not only for their understanding, love and care, but also their continue support during these three years.

© COPYRIGHT UPM

I certify that an Examination Committee met on ____________ to conduct the final examination of Hoe Pik Kheng on her Master thesis entitled “Effect of Entomopathogenic Fungus, *Metarhizium anisopliae* on *Coptotermes curvignathus* (Blattodea: Rhinotermitidae)” in accordance with Universiti Putra Malaysia (Higher Degree) Act 1980 and Universiti Pertanian (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Prof. Dr. Japar Sidik Bujang
Dean, Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia Campus Sarawak Bintulu

Dr. Lau Wei Hong
Department of Plant Protection
Faculty of Agriculture
Universiti Putra Malaysia
43400 UPM Serdang

Dr. Ganesan Vadamalai
Department of Plant Protection
Faculty of Agriculture
Universiti Putra Malaysia
43400 UPM Serdang

Prof. Lee Chow Yang
School of Biological Sciences
Universiti Sains Malaysia
11800 USM Minden, Penang

____

Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

© COPYRIGHT UPM

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. Members of the Supervisory Committee were as follows:

Joseph Bong Choon Fah, PhD
Associate Professor
Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia
Bintulu Sarawak Campus
(Chairman)

Jugah Kadir, PhD
Associate Professor
Universiti Putra Malaysia
(Member)

Rajan Amartalingam, PhD
Associate Professor
Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia
Bintulu Sarawak Campus
(Member)

HASANAH MOHD GHAZALI, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 9 December 2010

© COPYRIGHT UPM

DECLARATIONS

I hereby declare that the thesis is based on my original work except for quotations and citation, which have been duly acknowledged. I also declare that it has not been previously or concurrent submitted for any degree at Universiti Putra Malaysia or other institutions.

HOE PIK KHENG

Date: 3 September 2010

© COPYRIGHT UPM

TABLE OF CONTENTS

© COPYRIGHT UPM

LIST OF TABLES

© COPYRIGHT UPM

LIST OF FIGURES

© COPYRIGHT UPM

© COPYRIGHT UPM

© COPYRIGHT UPM

LIST OF ABBREVATIONS

ha	Hectare
e.g.	Example
ODA	Oatmeal Dodine Agar
DTA	Doberski and Tribe Agar
VFA	Veen and Ferron Agar
MAA	*Metarhizium anisopliae* selective media
K_2HPO_4	Dipotassium hydrogen phosphate
KH_2PO_4	Potassium dihydrogen phosphate
MgSO4. $7H_2O$	Magnesium sulphate hydrate
CTAB	hexadecyl tri-methyl ammonium bromide
cm	centimetre
ml	millilitre
^oC	degree Celcius
PDA	Potato Dextrose Agar
PDAY	Potato Dextrose Agar with 1% yeast extract
SDA	Sabaroud Dextrose Agar
SDAY	Sabaroud Dextrose Agar with 1% yeast extract
mm	mililiter
ANOVA	Analysis of Variance
DNA	Deoxy ribonucleic acid
PCR	Polymerase Chain Reaction
$MgCl_2$	Magnesium chloride
dNTP	Deoxy nucleotide triphosphate

© COPYRIGHT UPM

µl	Microlitre
TBE	Tris-borate EDTA
EDTA	Ethylenediaminetetraacetic acid
UV	Ultra-violet
BLAST	Basic Local Alignment Search Tool
RH	Relative humidity
DNMRT	Duncan New Multiple Range Test
Var.	variety
v/v	Volume per volume

© COPYRIGHT UPM

CHAPTER 1

INTRODUCTION

Coptotermes curvignathus Holmgren, a serious termite pest classified under the subfamily of Rhinotermitidae, causes serious damage in oil palm plantations especially in Malaysia and Indonesia (Cheng *et al*., 2008; Bong and King, 2006; Lim and Silek, 2001; Zulkefli *et al*., 2000; Sudharto *et al*., 1991; Wood, 1968). Termite infestation is a major concern in oil palm plantations especially those that are located in peat areas. This is because the planting of oil palm is extended to the peat areas. In Sarawak, the expansion of oil palm increased from 460,000 ha to nearly 800,000 ha within these five years. This termite species attacks the living tissues and eventually kill the palms. Currently, the control measures of *C. curvignathus* infestation in oil palms is still limited to conventional methods, such as drenching and trunk injection of insecticides (Lim and Silek, 2001; Sudharto *et al*., 1991). These forms of control are not only very costly; but bring adverse effects to the environment as most of the insecticides (chloropyrifos, fipronil, imidacloprid) used are highly soluble in water and are highly toxic. Hence, alternative control strategies are needed to curb the termite infestation problem in oil palm plantations on peat.

Biological control of subterranean termites with pathogenic fungi is a promising alternative to chemical control as it is generally perceived as providing both long-lasting insect control and having less potential for damage to the environment or non-target organisms than chemical

© COPYRIGHT UPM

interventions (Castrillo *et al*., 2005; Lord, 2005; Sun *et al*., 2002; Khetan, 2001; Grace, 1997; Hokkanen and Lynch, 1995; Howarth, 1991). Entomopathogenic fungi, such as *Metarhizium anisopliae* (Metchnikoff) Sorokin, have the ability to invade a host upon landing of the fungal conidia on the host by penetrating its cuticle, followed by a series of infection processes (Castrillo *et al*., 2005; Moino Jr. *et al*., 2002; St. Leger *et al*., 1993; St. Leger *et al*., 1991; Goettel *et al*., 1989; Hanel, 1982).

Termites are social insects where individual interacts with one another through several social behaviours like grooming, feeding and other forms of contact communications. These social interactions are important factors for considerations when a biological control agent, such as an entomopathogenic fungus, is being used on the termites. It is during these activities that horizontal transmission of fungal conidia happen, thus creating an epizootic within the colony (Sun *et al*., 2002; Rosengaus and Tranillo; 1997; Grace and Zoberi, 1992; Kramm *et al*., 1982). However, termites also have defensive mechanisms such as allogrooming and necrophagy that halt the spread of conidia and disease within the colony (Yanagawa and Shimizu, 2007; Zoberi, 1995; Logan *et al*., 1990; Rosengaus *et al*., 1988b; Su *et al*., 1982). Termite excretions, like fecal pellets or sheeting, and volatiles are also suggested to reduce the fungal growth (Wright *et al*., 2000; Chen *et al*., 1998; Rosengaus *et al*., 1998a).

During the application of a biological control agent, the termites' social behaviours like grooming and trophallaxis were needed. However, some of the termites' behaviours like allogrooming, necrophagy and several cellular

© COPYRIGHT UPM

defence mechanisms will curb the spread of fungal disease (Chouvenc *et al*., 2009a; Chouvenc *et al*., 2009b; Yanagawa *et al*., 2009; Yanagawa *et al*., 2008; Yanagawa and Shimizu, 2007; Wang and Powell, 2004; Myles, 2002a; Rosengaus *et al*., 1998a). Hence, the search for an entomopathogen that can withstand the harsh local environment of the peat soil and cope with the defence mechanisms of the termites in the field colony and thus initiate disease epizootics is essential and must be taken into account. The best fungal pathogens for termite control must be adapted for the living environment and have characteristics like quick and high sporulation (Sun *et al*., 2002; Goettel *et al*., 2000; Fuxa, 1989). Most species or isolates within species of the fungal pathogens like entomopathogenic fungi behave very differently and vary in terms of insect host range, infection levels, conidial germination rates and temperature requirements (Shah and Pell, 2003; Shaw *et al*., 2002; Pell *et al*., 2001; Sierotzki *et al*., 2000). The infection process of each entomopathogen varies and it is essential to recognize the process as it contributes to the virulence of an isolate. It is also essential to find a suitable application technique for the entomopathogen, *M. anisopliae* in the field to enhance the effect of the potential isolates.

Thus, the main objective of this research was to find a suitable *M. anisopliae* isolate as an alternative method to control *C. curvignathus* in oil palm plantations on peat. This objectives can be achieved by the following specific objectives 1) to isolate and characterize of local isolates of *M. anisopliae,* 2) to evaluate the virulence of locally isolated *M. anisopliae* against *C. curvignathus*, 3) to study the defence behaviour of *C. curvignathus* against

© COPYRIGHT UPM

locally isolated *M. anisopliae, 4)* to study the infection process that contribute to the virulence of potential isolates of *M. anisopliae* and 5) to evaluate several delivery methods of locally isolated *M. anisopliae* in laboratory trials.

© COPYRIGHT UPM

REFERENCES

Asensio, L., T. Carbonell, J.A. López-Jiménez and L.V. López-Llorca. 2003. Entomopathogenic fungi in soils from Alicante province. *Spanish Journal of Agriculture Research*, **3**: 37-45.

Bahiense, T.C., E.K.K. Fernandes and V.R.E.P. Bittencourt. 2006. Compatibility of the fungus *Metarhizium anisopliae* and deltamethrin to control a resistant isolate of *Boophilus microplus* tick. *Veterinary Parasitology*, **141**: 319-324.

Bateman, R.P., O.K. Douro-Kpindou, C. Kooyman, C. Lomer and Z. Ouambama. 1998. Some observation on the dose transfer of mycoinsecticide sprays to desert locust. *Crop Protection*, **17**: 151-158.

Bidochka, M.J., and G.G. Khachatourians. 1992. Growth of the entomopathogenic fungus *Beauveria bassiana* on cuticular components from the migratory grasshopper, *Melanoplus sanguinepes*. *Journal of Invertebrate Pathology*, **59**: 165-173.

Bidochka, M.J., J.E. Kasperski, G.A.M. Wild. 1998. Occurence of the entomopathogenic fungi *Metarhizium anisopliae* and *Beauveria bassiana* in soils from temperate and near-northern habitats. *Canadian Journal of Botany*, 76: 1998-1204.

Bong, C.F.J. and J.H. King. 2006. An assessment of termite infestation of oil palm on peat. Bulletin UPMKB 01-2006. Universiti Putra Malaysia Bintulu Campus, Bintulu, Sarawak.

Bong, C.FJ. and S.N. Liew. 2004. Early establishment of oil palm on peat. *The Planter,* **80**:563-570.

Boucias, D.G., J.C. Pendland and J.P. Latge. 1988. Nonspecific factors involved in attachment of entomopathogenic deuteromycetes to host insect cuticle. *Applied and Environmental Microbiology*, **54**: 1795-1805.

Bruck, D.J., J.E. Snelling, A.J. Dreves and T.J. Stefan. 2005. Laboratory bioassays of entomopathogenic fungi for control of *Delia radicum* (L.) larvae. *Journal of Invertebrate Pathology*, **89**: 179-183.

Bruck, D.J. 2004. Natural occurrence of entomopathogens in Pacific Northwest nursery soils and their virulence to the black vine weevil, *Otiorhynchus sulcatus* (F.) (Coleoptera: Curculionidae). *Environmental Entomology*, **33**: 1335-1343.

© COPYRIGHT UPM

Butt, T.M., C.W. Jackson and N. Magan. 2001. Introduction – Fungal biological control agents: progress, problems and potential. In *Fungi as biocontrol agents – progress, problems and potential*, ed. Butt, T.M., C.W. Jackson and N. Magan pp. 1-8. Wallingford:CAB International.

Butt, T.M and M.S. Goettel. 2000. Bioassays of entomogenous fungi. In *Bioassays of entomopathogenic microbes and nematodes,* ed. A. Navon and K.R.S. Ascher, pp. 141-195. Wallingford: CAB International

Carswell, I., R. Spooner-Hart and J.R. Milner. 1998. Laboratory susceptibility of *Musca domestica* L. (Diptera: Muscidae) and *Bactrocera tryoni* (Frogatt) (Diptera: Tephritidae) to an isolate of *Metarhizium anisopliae* (Metsch.) Sorokin. *Australian Journal of Entomology*, **37**: 281-284.

Castrillo, L.A., D.W. Roberts and J.D. Vandenberg. 2005. The fungal past, present and future: germination, ramification and reproduction. *Journal of Invertebrate Pathology,* **89**: 46-56.

Chan, S.P. and C.F.J. Bong. 2008. Susceptible of planted forest species to Coptotermes curvignathus Holmgren. In 4th Life Science Postgraduate Conference – 2nd Penang International Postgraduate Convention. 18-20 June 2008. USM, Malaysia (Abstract).

Chandler, D., D. Hay and A.P. Reid. 1997. Sampling and occurrence of entomopathogenic fungi and nematodes in UK soils. *Applied Soil Ecology*, **5**: 133-141.

Chase, A.R., L.S. Osborne, and V.M. Ferguson. 1986. Selective isolation of the entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* from an artificial potting medium. Florida Entomologists, **69**: 285-292.

Chen, J., G. Henderson, C.C. Grimm, S.W. Lloyd and R.A. Laine. 1998. Termite fumigate their nest with naphthalene. *Nature,* **392**: 558-559.

Cheng, S., L.G. Kirton and S. Gurmit. 2008. Termite attack on oil palm grown on peat soil: identification of pest species and factors contributing to the problem. *The Planter,* **84**: 659-670

Cherry, A.J., P. Abalo and K. Hell. 2005. A laboratory assessment of the potential different isolates of the entomopathogenic fungi *Beauveria bassiana* (Balsamo) Vuillemin and *Metarhizium anisopliae* (Metchnikoff) to control *Callosobruchus maculates* (F.) (Coleoptera: Bruchidae) in stored cowpea. *Journal of Stored Products Research,* **41**: 295-309.

Chouvenc, T., N.Y. Su and A. Robert. 2009a. Inhibition of *Metarhizium anisopliae* in the alimentary tract of the eastern subterranean termites *Reticulitermes flavipes*. *Journal of Invertebrate Pathology*, **101**: 130-136.

© COPYRIGHT UPM

Chouvenc, T., N.Y. Su and A. Robert. 2009b. Cellular encapsulation in the eastern subterranean termites, *Reticulitermes flavipes* (Isoptera), against infection by entomopathogenic fungus *Metarhizium anisopliae*. *Journal of Invertebrate Pathology*, **101**: 234-241.

Chouvenc, T., N.Y. Su and M.I. Elliot. 2008a. Antifungal activity of the termite alkaloid norharmane against the mycelia growth of *Metarhizium anisopliae* and *Aspergillus nomius*. *Journal of Invertebrate Pathology*, **99(3)**: 345-347.

Chouvenc, T., N.Y. Su and M.I Elliot. 2008b. Interaction between the subterranean termite *Reticulitermes flavipes* (Isoptera: Rhinotermitidae) and the entomopathogenic fungi *Metarhizium anisopliae* in foraging arenas. *Journal of Economic Entomology*, **101**: 885-893.

Cornelius, M.L. and J.K Grace. 1995. Laboratory evaluations of three ant species with the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Sociobiology*, **26**: 291-298.

Cornelius, M.L. and J.K Grace. 1996. Effect of two ant species (Hymenoptera: Formicidae) on the foraging and survival of the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Environmental Entomology,* **25**: 85-89.

Cornelius, M.L. and J.K Grace. 1997. Effect of termite soildiers on the foraging behaviour of *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in the presence of predatory ants. *Sociobiology,* **29**: 247-253.

Cornelius, M.L., J.K. Grace and J.R. Yates. 1997. Toxicity of monoterpenoids and other natural products to the Formosan subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology,* **90**: 320-325.

Daoust, R.A., M.G. Ward and Roberts, D.W. 1982. Effect of formulation on the virulence of *Metarhizium anisopliae* conidia against mosquito larvae. *Journal of Invertebrate Pathology*, **40**: 228-236.

De La Rosa, W., R. Alatorre, J.F. Barrera and C. Toriello. 2000. Effect of *Beauveria bassiana* and *Metarhizium anisopliae* (Deuteromycetes) upon the Coffee Berry Borer (Coleoptera: Scolytidae) under field conditions. *Journal of Economic Entomology*, **93**: 1409-1414.

Destéfano, R.H.R., S.A.L. Destéfano and C.L. Messias. 2004. Detection of *Metarhizium anisopliae* var. *anisopliae* within infected sugarcane borer *Diatraea saccharalis* (Lepidoptera: Pyralidae) using specific primers. *Genetics and Molecular Biology*, **27**: 245-252.

© COPYRIGHT UPM

Dhanarajan, G. 1978. Cannibalism and necrophagy in a subterranean termite (*Reticulitermes lucifugus* var. *santonensis*). *Malayan Nature Journal*, **31**: 237-251.

Doberski, J.W. and H.T. Tribe. 1980. Isolation of entomogenous fungi from elm bark and soil with reference to ecology of *Beauveria bassiana* and *Metarhizium anisopliae. British Mycological Society*, **74**: 95-100.

Doberski, J.W. 1981. Comparative laboratory studies on three fungal pathogens of the elm bark beetle *Scolytus scolytus*: Pathogenicity of *Beauveria bassiana*, *Metarhizium anisopliae*, and *Paecilomyces farinosus* to larvae and adults of *S. scolytus. Journal of Invertebrate Pathology*, **37**: 188-194.

Dong, C., J. Zhang, H. Huang, W. Chen and Y. Hu. 2009. Pathogenicity of a new China variety of *Metarhizium anisopliae* (*M. anisopliae* var. *Dcjhyium*) to subterranean termite *Odontotermes formosanus. Microbiological Research,* **164**: 27-35.

Dong, C., J. Zhang, W. Chen, H. Huang and Y. Hu. 2007. Characterization of a newly discovered China variety of *Metarhizium anisopliae* (*M. anisopliae* var. *dcjhyium*) for virulence to termites, isoenzyme, and phylogenetic analysis. *Microbiological Research*, **162**: 53-61.

Eggleton, P. 2001. Termites and trees: a review of recent advances in termite phylogenetics. *Insectes Sociaux,* **38**:187-193.

Fuxa, J.R. 1987. Ecological considerations for the use of entomopathogens in IPM. *Annual Review of Entomology,* **32**: 225-251.

Fuxa, J.R. 1989. Importance of epizootiology to biological control of insects with virus. *Mem. Inst. Oswaldo Cruz, Rio de Janeiro,* **84**: 81-88.

Garraway, M.O. and R.C. Evans. 1984. Fungal nutrition and physiology. pp. 71-123. USA:John Wiley and Sons, Inc.

Gay, F.J. 1969. Species introduced by man. In *Biology of termites, vol. 1, ed.* K.Krishna and F,M Weesner, pp. 459-491 New York :Academic Press.

Gillespie, J.P., M.R. Kanost and T. Trenczek. 1997. Biological mediators of insect immunity. *Annual Review of Entomology,* **42**: 611-643.

Goettel, M.S. 1984. A simple method for mass culturing entomopathogenic Hyphomycete fungi. *Journal of Microbiological Methods*, **3**: 15-20.

Goettel, M.S., R.J. St. Leger, N.W. Rizzon, R.C. Staples and D.W. Roberts. 1989. Ultrastructural localization of a cuticle-degrading protease produced by the entomopathogenic fungus *Metarhizium anisopliae* during penetration of host (*Manduca sexta*) cuticle. *Journal of General Microbiology*, **135**: 2233-2239.

© COPYRIGHT UPM

Goettel, M.S., G.D. Inglis and S.P. Wraight. 2000. Fungi. In *Field manual of techniques in invertebrate pathology: application and evaluation of pathogens for control of insects and other invertebrate pests,* ed. L.A. Lacey and H.K. Kaya, pp. 255-282. Dordrect:Kluwer Academic.

Grace, J.K. 1997. Biological control strategies for suppression of termites. *Journal of Agricultural Entomology*, **14**: 281-289.

Grace, J.K. and M.H. Zoberi. 1992 Experimental evidence for transmission of *Beauveria bassiana* by *Reticulitermes flavipes* workers (Isoptera: Rhinotermitidae). *Sociobiology,* **20**: 23-28

Gupta, S.C., T.D. Leathers, G. N. El-Sayed and C.M. Ignoffo. 1992. Insect cuticle-degrading enzymes from the entomogenous fungus *Beauveria bassiana*. *Experimental Mycology*, **16**: 132-137.

Hajek, A.E. and St. Leger, R.J. 1994. Interactions between fungal pathogens and insect hosts. *Annual Review of Entomology*, **39**: 294-322.

Hall, T.A. 1999. BioEdit: a user friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. *Nucl. Acids Symp. Ser*. **41**:95-98.

Hanel, H. 1982. The life cycle of the insect pathogenic fungus *Metarhizium anisopliae* in the termite *Nasutitermes exitiosus*. *Mycopathologia* **80**: 137-145.

Harris, W.V. 1969. Termites: their recognition and control. London:Longman.

Hickin, N.E. 1971. *Termites. A world problem*. London:Hutchinson and Co Ltd.

Hoe, P.K. and C.F.J. Bong. 2008. Termite diversity in oil palm plantation. In 4th Life Science Postgraduate Conference – 2nd Penang International Postgraduate Convention. 18-20 June 2008. USM, Malaysia (Abstract).

Hokkanen, H., and Lynch, J.M. 1995. *Biological control: benefits and risks*. Cambridge: Cambridge University Press.

Holdobbler, B. and E.O. Wilson. 1990. *The ants*. Cambridge:Belknap Press

Horton, D.R. and J. Moore. 1993. Behavioural effects of parasites and pathogens in insect hosts. In *Parasites and pathogens of insects, vol. 1,* ed. N.E. Beckage, S.N. Thompson and B.A. Federici, pp. 107-124. New York:Academic Press.

Howarth, F.G. 1991. Environmental impacts of classical biological control. *Annual Review of Entomology,* **36**: 485-509.

© COPYRIGHT UPM

Howse, P.E. 1964a. The significance of sound produced by the termite *Zootermopsis angusticollis* (Hagen). *Animal Behaviour,* **12**: 284-300.

Howse, P.E. 1964b. An investigation into mode of action of subgenal organi in the termite *Zootermopsis angusticollis* Emerson, and in the cockroach, *Periplaneta americana* L. *Journal of Insect Physiology,* **10**: 409-424.

Howse, P.E. 1965. On the significance of certain oscillatory movements of termites. *Insectes Sociaux,* **12**: 335-345.

Huxham, I.M., K.D.Z. Samuels, J.B. Heale and N.J. McCorkindale. 1989. In vivo and in vitro assays for pathogenicity of wild-type and mutant strains of *Metarhizium anisopliae* for three insect species. *Journal of Invertebrate Pathology*, **53**: 143-151.

Ibrahim, L., T.M. Butt and P. Jenkinson. 2002. Effect of artificial culture media on germination, growth, virulence and surface properties of the entomopathogenic hyphomycete *Metarhizium anisopliae*. *Mycological Research*, **106**: 705-715.

Inglis, G.D., M.S. Goettel, T.M. Butt and H. Strasser. 2001. Use of hyphomycetous fungi for managing insect pests. In *Fungi as biocontrol agents – progress, problems and potential*, ed. Butt, T.M., C.W. Jackson and N. Magan pp. 23-70. Wallingford: CAB International.

Inward, D., G. Beccaloni and P. Eggleton. 2007. Death of an order: a comprehensive molecular phylogenetic study confirms that termites are eusocial cockroaches. *Biology Letters.* **3**:564-565

Jackson, T.A., S.B. Alves and R.M. Pereira. 2000. Success in biological control of soil-swelling insect by pathogens and nematodes. In *Biological Control: measures of success*, ed. G. Gurr and S. Wratten, pp. 271:296. London: Kluwer Academic Press.

Jones, W.E., J.K. Grace and M. Tamashiro. 1996. Virulence of seven isolates of *Beauveria basisana* and *Metarhizium anisopliae* to *Coptotermes formosanus* (Isoptera: Rhinotermitidae). *Environmental Entomology,* **25**: 481-487.

Kambhampati, S. and P. Eggleton. 2000. Phylogenetics and taxanomy. In *Termites: evolution, sociality, symbioses, ecology*, ed. T. Abe, D.E. Bignell, M. Higashi, pp. 1-23. Dordrecht: Kluwer Academic Publishing.

Kard, B.M. and E.J. Mallette.1997. Resistance of six wood products using panelling to *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). *Journal of Economic Entomology,* **90**: 178-182.

Keller, S. and G. Zimmerman. 1989. Mycopathogens of soil insects. In *Insect-fungus interactions*, ed. N. Wilding, N.M. Collins, P.M. Hammond and J.F. Webber, pp. 240-265. London:Academic Press.

© COPYRIGHT UPM

Kessler, P., H. Matzke and S. Keller. 2003. The effect of application time and soil factors on the occurrence of *Beauveria brongniartii* applied as a biological control agent in soil. *Journal of Invertebrate Pathology*, **84**: 15-23.

Khetan, S.K. 2001. *Microbial pest control*. New York:Marcel Dekker.

Klingen, I., J. Eilenberg and R. Meadow. 2002. Effects of farming system, field margins and bait insect on the occurrence of insect pathogenic fungi in soils. *Agriculture Ecosystems and Environment*, **91**: 191-198.

Kramm, K.R., D.F. West and P.G. Rockenbach. 1982. Termites pathogens: transfer of the entomopathogen Metarhizium anisoplie between Reticulitermes sp. termites. *Journal of Invertebrate Pathology*, **40**: 1-6

Kramm, K.R. and D.F. West. 1982. Termite pathogens: effects of ingested *Metarhizium*, *Beauveria* and *Gliocladium* conidia on termites (*Reticulitermes* sp.). *Journal of Invertebrate Pathology* **40**: 7-11.

Krisha, K. and F.M. Weesner. 1969. *Biology of termite, volume 1*. New York:Academic Press

Lee, C.Y., C. Vongkaluang and M. Lenz. 2007. Challenges to subterranean termite management of multi-genera faunas in Southeast Asia and Australia. *Sociobiology*, **50(1)**: 213-221.

Lee, C.Y. 2002a. Control of foraging colonies of subterranean termites, *Coptotermes travians* (Isoptera: Rhinotermitidae) in Malaysia using hexaflumuron baits. *Sociobiology*, **39**: 411-416.

Lee, C.Y. 2002b. Subterranean termite pests and their control in the urban environment in Malaysia. *Sociobiology*, **40(1)**: 3-9.

Leucona, R., J. Clement, G. Riba, D. Joulie and P. Juarez. 1997. Spore germination and hyphal growth of *Beauveria* sp. on insect lipids. *Journal of Economic Entomology*, **90**: 119-123.

Lim, K.H. and B. Silek. 2001. Termite infestation on oil palms planted on deep peat in Sarawak: Tradewinds experience. *Proceedings of the 2001 PIPOC International Palm Oil Congress (Agriculture).*

Liu, S.D., S.C. Lin and J.F. Shiau. 1989. Microbial control of coconut leaf beetle (*Brontispa longissima*) with green muscardine fungus, *Metarhizium anisopliae*. *Journal of Invertebrate Pathology*, **53**: 307-314.

Lo, N., G. Tokuda, H. Watanabe, H. Rose, M. Slaytor, K. Maekawa, C. Bandi and H. Noda. 2000. Evidence from multiple gene sequence indicates

© COPYRIGHT UPM

that termites evolved from wood-feeding cockroaches. *Current Biology*, **10**: 801-804.

Logan, J.W.M. and R.H. Cowie and T.G. Wood. 1990. Termite (Isoptera) control in agriculture and forestry by non-chemical methods: a review. *Bulletin of Entomological Research,* **80**: 309-330.

Lord, J.C. 2005. From Metchinikoff to Monsanto and beyond: The path of microbial control. *Journal of Invertebrate Pathology,* **89**: 19-29.

Maniania, N.K., S. Sithanantham, S. Ekesi, K. Ampong-Nyarko, J. Baumgärtner, B. Löhr, C.M. Matoka. 2003. A field trial of the entomogenous fungus *Metarhizium anisopliae* for control of onion thrips, *Thrips tabaci*. *Crop Protection,* **22**: 553-559.

Meyling, N.V. and J. Eilenberg. 2006. Occurrence and distribution of soil borne entomopathogenic fungi within single organic agroecosystem. Agriculture *Ecosystems and Environment*, **113**: 336-341.

Milner, R.J., J.A. Staples and G.G. Lutton. 1992. The effect of humidity on germination and infection of termites by the Hyphomycete, *Metarhizium anisopliae*. *Journal of Invertebrate Pathology,* **69**:53-59.

Milner, R.J., J.A. Staples, T.R. Hartley, G.G. Lutton, F. Driver and J.A.L. Watson. 1998a. Occurence of *Metarhizium anisopliae* in nests and feeding sites of Australian termites. *Mycological Research,* **102**: 216-220.

Milner, R.J., J.A. Staples, T.R. Hartley and G.G. Lutton. 1998b. The selection of an isolate of the hyphomycete fungus*, Metarhizium anisopliae*, for control of termites in Australia. *Biological Control*, **11**: 216-220.

Moino Jr. A., S.B. Alves, R.B. Lopes, P.M. Oliveira, J. Neves, R M. Pereira and S A. Vieira. 2002. External development of the entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* in the subterranean termite *Heterotermes tenius. Scientia Agricola*, **59**: 267-273.

Myles, T,G. 2002a. Observations on Mites (Acari) associated with the Eastern Subterranean termite, *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). *Sociobiology*, **39**: 277-280.

Myles, T.G. 2002b. Laboratory studies on the transmission of *Metarhizium anisopliae* in the Eastern Subterranean Termite, *Reticulitermes flavipes* (Isoptera: Rhinotermitidae), with a method for applying appropriate doses of conidia to trapped termites for release. *Sociobiology*, **40**: 265-276.

© COPYRIGHT UPM

Myles, T.G. 2002c. Review of termite biocontrol agents with methods of isolation, culture, and dosing of *Metarhizium anisopliae*. *Sociobiology*, **40**: 256-276.

Myles, T.G. 2002d. Alarm, aggregation, and defense by *Reticulitermes flavipes* in response to a naturally occurring isolate of *Metarhizium anisopliae*. *Sociobiology*, **40**: 243-255.

Ngee, P.S., A. Tashiro, T. Yoshimura, Z. Jaal and C.Y. Lee. 2004. Wood preference of selected Malaysian subterranean termites (Isoptera: Rhinotermitidae, Termitidae). Sociobiology, **43**:535-550.

Pearce, 1987. Seals, tombs, mummies and tunnelling in the drywood termite *Cryptotermes* (Isoptera: Kalotermitidae). *Sociobiology*, **13**: 217-226.

Pearce, M.J. 1997. *Termites. Biology and pest management*. UK:CAB International, UK.

Pearce, M.J. and B.S. Waite. 1994. A list of termite genera (Isoptera) with comments on taxanomic changes and regional distribution. *Sociobiology*, **23**: 247-259.

Pell, J.K., J. Eilenberg, A.E. Hajek and D.C. Steinkraus. 2001. Biology, ecology and pest management potential of Entomophthrales. In *Fungi as biocontrol agents: progress, problems and potential*, ed. T.M. Butt, C. Jackson and N. Magan, pp. 71-153. Wallingford:CAB International

Quesada-Moraga, E., J.A. Navas-Cortés, E.A.A. Maranhao, A. Ortiz-Urquiza and C. Santiago-Alvarez. 2007. Factors affecting the occurrence and distribution of entomopathogenic fungi in natural and cultivated soils. *Mycological Research*, **111**: 947-966.

Quesada-Moraga, E., R. Santos-Quirós, P. Valverde-Garcia and C. Santiago-Alvarez. 2004. Virulence, horizontal transmission, and sublethal reproductive effects of *Metarhizium anisopliae* (Anamorphic fungi) on the German cockroach (Blattodea: Blattellidae). *Journal of Invertebrate Pathology*, **87**: 51-58.

Ramle, M., W. Mohd Basri, K. Norman, A.A. Siti Ramlah, H. Noor Hisham. 2006. Research into the commercialization of *Metarhizium anisopliae* (Hyphomycetes) for biocontrol of the rhinoceros beetle, *Oryctes rhinoceros* (Scarabaeidae), in oil palm. *Journal Oil Palm Research*. **Special issue – April 2006**: 37-49.

Ramle, M., W. Mohd Basri, K. Norman, S. Mukesh, and A.A. Siti Ramlah. 1999. Impact of *Metarhizium anisopliae* (Deuteromycotina: Hyphomycetes) applied by wet and dry inoculums on oil palm rhinoceros beetle, *Oryctes rhinoceros* (Coleoptera: Scarabaeidae). *Journal of Oil Palm Research*. **11**: 25-40.

© COPYRIGHT UPM

Rangel, D.E.N., D.G. Alston and D.W. Roberts. 2008. Effects of physical and nutritional stress conditions during culture on conidial germination speed, adhesion to host cuticle, and virulence of *Metarhizium anisopliae*, an entomopathogenic fungi. *Mycological Research*, 112:1355-1361.

Rath, A.C., T.B. Koen and H.Y. Yip. 1992. The influence of abiotic factors on the distribution and abundance in *Metarhizium anisopliae* in Tasmanian pasture soils. *Mycological Research*, **96**: 378-384.

Rath, A. C. 2000. The use of entomopathogenic fungi for control of termites. *Biocontrol Science and Technology*, **10**: 563-581.

Roberts, D.W. and W.G. Yendol. 1971. Use of fungi for microbial control of insects. Use of fungi for microbial control of insects. In *Microbial control of insects and mites,* ed. H.D. Burgess and N.W. Hussey pp. 125-149. London:Academic press.

Robinson, J.B.D. 1958. Some chemical characteristics of “Termite Soils” in Kenya coffee fields. *Journal of Soil Science,* **9**: 58-65.

Rosengaus, R.B. and J.F.A. Traniello. 1997. Pathobiology and disease transmission in dampwood termites [*Zootermopsis angusticollis* (Isoptera: Termopsidae)] infected with the fungus *Metarhizium anisopliae* (Deuteromycotina: Hyphomycetes). *Sociobiology,* **30**: 185-195.

Rosengaus, R.B., R.M. Guldin, and J.F.A. Traniello. 1998a. Inhibitory effect of termite fecal pellet on fungal spore germination. *Journal of Chemical Ecology,* **24**: 125-134.

Rosengaus, R.B., R.M Guldin and J.F.A. Traniello. 1998b. Disease resistance: a benefit of sociality in the dampwood termite *Zootermopsis angusticollis* (Isoptera: Termopsidae). *Behavourial Ecology and Sociobiology,* **44**: 125-134.

Safavi, S.A., F.A. Shah, A.K. Pakdel, G.R. Rasoulian, A.R. Bandan and T.M. Butt. 2007. Effect of nutrition on growth and virulence of the entomopathogenic fungi *Beauveria bassiana*. *FEMS Microbiology Letters*, **270**: 116-123.

Sajap, A, S., S. Amit and J. Welker. 2000. Evaluation of hexaflumuron for controlling the subterranean termite *Coptotermes curvignathus* (Isoptera: Rhinotermitidae) in Malaysia. *Journal of Economic Entomology*, **93**: 429-433.

Sajap, A.S., A.B. Atim, H. Husin and Y.A. Wahab. 1997. Isolation of *Conidiobolus coronatus* (Zygomycetes: Entomophthorales) from soil and its effect on *Coptotermes curvignathus* (Isoptera: Rhinotermitidae). *Sociobiology,* **30**: 257-262.

© COPYRIGHT UPM

Sajap, A.S. and K. Kaur. 1990. Histopathology of *Metarhizium anisopliae*, an entomopathogenic fungus, infection in the termite, *Coptotermes curvignathus*. *Pertanika*, **13**: 331-334.

Samson, R.A., H.C. Evans and J.P. Latgé. 1988. Atlas of entomopathogenic fungi. New York:Springer Berlin Heidelberg.

Samson, P.R., R.J. Milner, E.D. Sander and G.K. Bullard. 2005. Effect of fungicides and insecticides applied during planting of sugarcane on viability of *Metarhizium anisopliae* and its efficacy against white grubs. *BioControl*, **50**: 151-163.

Samuels, K.D., J.B. Heale and M. Llewellyn. 1989. Characteristics relation to the pathogenicity of *Metarhizium anisopliae* toward *Nilaparvata lugens*. *Journal of Invertebrate Pathology*, **53**: 25-31.

Shah, P.A. and J.K. Pell. 2003. Entomopathogenic fungi as biological control agents. *Applied Microbiology Biotechnology*, **61**: 413-423.

Shah, F.A. and T.M. Butt. 2005. Influence of nutrition on the production and physiology of sectors produced by the insect pathogenic fungus *Metarhizium anisopliae*. *FEMS Microbiology Letters,* **250**: 201-207.

Shah, F.A., C.S. Wang and T.M. Butt. 2005. Nutrition influences growth and virulence of the insect-pathogenic fungus *Metarhizium anisopliae*. *FEMS Microbiology Letters,* **251 (2)**: 259-266.

Shaw, K.E., G. Davidson, S.J. Clark, B.V. Ball, J.K. Pell, D. Chandler and K.D. Sunderland. 2002. Laboratory bioassays to assess the pathogenicity of mitosporic fungi to *Varroa destructor* (Acari: Mesostigmata), an ectoparasitic mite of the honey bee, *Apis mellifera*. *Biological Control*, **24**: 266-276.

Sierotzki, H., F. Camastral, P.A. Shah, M. Aebi and U. Tuor. 2000. Biological characteristics of selected *Erynia neoaphidis* isolates. *Mycological Research*, **104**: 213-219.

Smith, R.J. and E.A. Grula. 1981. Nutritional requirements of conidial germination and hyphal growth of *Beauveria bassiana*. *Journal of Invertebrate Pathology*, **37**: 222-230.

Sosa-Goméz, D. and F. Moscardi. 1998. Laboratory and field studies on the infection of stink bugs*, Nezera viridula, Piezodorus guildinii,* and *Euschistus heros* (Hemiptera: Pentatomidae) with *Metarhizium anisopliae* and *Beauveria bassiana* in Brazil. *Journal of Invertebrate Pathology*, **71**: 115-120.

© COPYRIGHT UPM

St. Leger, R.J., M. Goettel, D. W. Roberts and R. C. Staples.1991. Prepenetration events during infection of host cuticle *by Metarhizium anisopliae*. *Journal of Invertebrate Pathology*, 58: 168-179.

St. Leger, R.J. 1993. Biology and mechanisms of insect cuticle invasion by Deuteromycete fungal pathogens. In *Parasites and pathogens of insects, vol. 2*, ed. N.E. Beckage, S.N. Thompson and B.A. Federici, pp.211-225. New York:Academic Press

St. Leger, R.J., R.C. Richards and D.W. Roberts. 1993. Entomopathogenic isolates of *Metarhizium anisopliae*, *Beauveria bassiana* and *Aspergillus flavus* produce multiple extracellular chitinase isozymes. *Journal of Invertebrate Pathology*, **61**:81-84.

St. Leger, R.J., M.J. Bidochka and D.W. Roberts. 1994. Germination triggers of *Metarhizium anisopliae* conidia are related to host species. *Microbiology,* **140**: 1651-1660.

St. Leger, R.J., P.K. Durrands, A.K. Charnley and R.M. Cooper. 1988 Role of extracellular chymoelastase in the virulence of *Metarhizium anisopliae* for *Manduca sexta*. *Journal of Invertebrate Pathology*, **52**: 285-293.

St. Leger, R.J., A.K. Charnley and R.M. Cooper. 1986. Cuticle-degrading enzymes of entomopathogenic fungi: mechanisms of interaction between pathogen enzymes and insect cuticle. *Journal of Invertebrate Pathology*, **47**: 295-302.

Strack, B.H. 1998. *The role of social behaviour Reticulitermes flavipes (Kollar) (Isoptera: Rhinotermitidae) in defence against the fungal pathogen Metarhizium anisopliae (Metschnikoff) Sokorin (Deuteromycotina: Hyphomycetes),* Master Thesis, University of Toronto.

Staples, J.A. and R.J. Milner. 2000. A laboratory evaluation of the repellency of Metarhizium anisopliae conidia to *Coptotermes lacteus* (Isoptera: Rhinotermitdae). *Sociobiology*, **36**: 133-146.

Stuart, A.M. 1963a. The origin of the train in the termites *Nasutitermes coriger* (Motschulsky) and *Zootermopsis nevadensis* (Hagen). Isoptera. *Physiological Zoology*, **35**: 69-84.

Stuart, A.M. 1963b. Studies on the communication of alarm in the termite *Zootermopsis nevadensis* (Hagen). Isoptera. *Physiological Zoology,* **36**: 85-96.

Stuart, A.M. 1969. Social behaviour and communication. In *Biology of termites, vol. 2*, ed. K. Krishna and F.M. Weesner, pp. 193-229. New York:Academic Press.

© COPYRIGHT UPM

Sudharto, Ps., A. Sipayung and R. Desmier de Chenon. 1991. Termites – A new problem on oil palm plantations in Indonesia. *PORIM International Palm Oil Conference.*

Su, N.Y., M. Tamashiro, J.R. Yates and M.I. Haverty. 1982. Effect of behaviour on the evaluation of insecticides for prevention of or remedial control of the Formosan subterranean termite. *Journal of Economic Entomology,* **75**: 188-193.

Su, N.Y. and M. Tamashiro. 1987. An overview of the Formosan subterranean termite (Isoptera:Rhinotermitidae) in the world. In Biology and control of the Formosan subterranean termite. *Proceedings. The International Symposium on the Formosan subterranean termite (June, 1985)*, College Trop. Ag. Human Resources, University of Hawaii, Honolulu. pp. 3-15.

Su, N.Y. and R.H. Scheffrahn. 1990. Economically important termites in the United States and their control. *Sociobiology*, **17**: 77-94.

Su, N.Y. and R.H. Scheffrahn. 1998. A review of subterranean termite control practices and prospects for integrated pest management programs. *Integrated Pest Management Review,* **3**: 1-13.

Sun, J., J.R. Fuxa and G. Henderson. 2002. Sporulation of *Metarhizium anisopliae* and *Beauveria bassiana* on *Coptotermes formosanus* and in vitro. *Journal of Invertebrate Pathology,* **81**: 78-85.

Sun, J., J.R. Fuxa and G. Henderson. 2003. Virulence and in vitro characteristics of pathogenic fungi isolated from soil by baiting with *Coptotermes formosanus* (Isoptera: Rhinotermitidae). *Journal of Entomological Science*, **38**: 342-358.

Tanada, Y. and H.K. Kaya. 1993. *Insect pathology*. Academic press, San Diego.

Thapa, R.S. 1981. *Termites of Sabah*. Sabah Forest Record Number 12. Sandakan: Sabah Forest Department.

Tho, Y.P. 1992. *Termites of Peninsular Malaysia*. Malaysian Forest Records No. 36, Kepong :Forest Research Institute Malaysia.

Thompson, J.D., D.G. Higgins and T.J. Gibson. 1994. CLUSTAL W: Improving the sensitivity of progressive multiple sequence alignment through sequence weighting, positions-specific gap penalties and weight matrix choice. *Nucleic Acids Res.* **22**:4673-4680.

Vänninen, I. 1996. Distribution and occurrence of four entomopathogenic fungi in Finland: effect of geographical location, habitat type and soil type. *Mycological Research*, **100**: 93-101.

© COPYRIGHT UPM

Veen, K.H. and P. Ferron. 1966. A selective medium for isolation of *Beauveria tenella* and of *Metarhizium anisopliae*. *Journal of Invertebrate Pathology*, **8**: 268-269.

Vega, F.E., M.A. Jackson, G. Mercadier and T.J. Poprawski. 2003. The impact of nutrition on conidia yields for various fungal entomopathogens in liquid culture. *World Journal of Microbiology and Biotechnology*, **19**: 363-368.

Wang, C. and J.E. Powell. 2004. Cellulose bait improves the effectiveness of *Metarhizium anisopliae* as a microbial control of termites (Isoptera: Rhinotermitidae). *Biological Control*, **30**: 523-529.

Wang, C., J.E. Powell and B.M. O'Connor. 2002. Mites and nematodes associated with three subterranean termite species (Isoptera: Rhinotermitidae). *Florida Entomologist*, **85**: 499-506.

Wells, J.D., J.R. Fuxa and G. Henderson. 1995. Virulence of four fungal pathogens to *Coptotermes formosanus* (Isoptera: Rhinotermitidae). *Journal of Entomological Science,* **30**: 208-215.

Weseloh, R.M. and T.G. Andreadis. 1997. Persistance of resting spores of *Entomophaga maimaiga*, a fungal pathogen of the gypsy moth, *Lymantria dispar. Journal of Invertebrate Pathology*, **69**:195-196.

White, T.J., T. Bruns, S. Lee and J.W. Taylor. 1990. Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: *PCR Protocols: A Guide to Methods and Applications*, eds. Innis, M.A.D.H. Gelfand, J.I. Sninsky and T.J. White. pp. 315-322. New York:Academic Press, Inc.

Wilson, E.O. 1971. *The insect societies*. Cambridge:Belknap Press.

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

Wright, M.S., G. Henderson and J. Chen. 2000. Growth response of *Metarhizium anisopliae* of two Formosan subterranean termite nest volatiles, naphthalene and fenchone. *Mycologia,* **92**: 42-45.

Wright, M.S., W.L.A. Osbrink and A.R. Lax. 2002. Transfer of entomopathogenic fungi among Formosan subterranean termite and subsequent mortality. *Journal of Applied Entomology,* **126**:20-23.

Wyss, G.S., R. Charudattan and J.T. DeValerio. 2001. Evaluation of agar and grain mediafor mass production of conidia of *Dactylaria higginsii*. *Plant Disease*, **85**: 1165-1170.

Yaga, S. 1972. On the secretion of the termite Coptotermes formosanus Shiraki; the components of sugar and amino acids in the secretion of

© COPYRIGHT UPM

workers. *Science Bulletin* **19**: 481-188, College of Agriculture. University of Ryukus, Okinawa, Japan

Yanagawa, A. and S. Shimizu. 2007. Resistance of the termite, *Coptotermes formosanus* Shiraki to *Metarhizium anisopliae* due to grooming. *BioControl*, **52**: 75-85.

Yanagawa, A., F. Yokohari and S. Shimizu. 2008. Defense mechanism of the termite, *Coptotermes formosanus* Shiraki, to entomopathogenic fungi. *Journal of Invertebrate Pathology*, **97**: 165-170.

Yanagawa, A., F. Yokohari and S. Shimizu. 2009. The role of antennae in removing entomopathogenic fungi from cuticle of termite, *Coptotermes formosanus*. *Journal of Insect Science*, 9: 1-9.

Zoberi, M. 1995. *Metarhizium anisopliae*, a fungal pathogen of *Reticulitermes flavipes* (isopteran: Rhinotermitidae). *Mycologia*, **87**:354-359.

Zoberi, M. and J.K. Grace. 1990b. Isolation of the pathogen *Beauveria bassiana* from *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). *Mycologia,* **87**: 354-359.

Zoberi, M. and J.K. Grace. 1990a. Fungi associated with the subterranean termite *Reticulitermes flavipes* in Ontario. *Mycologia*, **92**: 289-294.

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

© COPYRIGHT UPM