THE 14th CONFERENCE OF PRTRG

PACIFIC RIM TERMITE RESEARCH GROUP

PRTRG 14

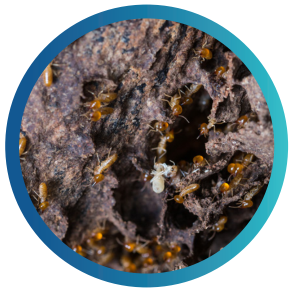
THAILAND

March 2-3, 2023

The 14th Conference of the Pacific rim Termite Research Group

PRTRG PACIFIC RIM TERMITE RESEARCH GROUP

Bangkok | Thailand



The 14th Conference of

PRTRG | Pacific Rim Termite Research Group

March 2 – 3, 2023

S Ratchada Leisure Hotel

Bangkok, Thailand

Organizer:

PACIFIC RIM TERMITE RESEARCH GROUP

Co-Organizer:

Kasetsart University

Thailand Pest Management Association (TPMA)

Sponsored by

2022 Environmental Science (Thailand) Co,. Ltd

Syngenta Crop Protection Limited

Groupe Berkem, France

Foreword of the President

Dear participants,

I am very pleased to welcome you all to the 14th International Conference of Pacific Rim Termite Research Group (PRTRG) in Bangkok, Thailand, on March 2 – 3, 2023.

The PRTRG Conference is a well-established biannual event at the PRTRG, devoted to gathering eminent speakers and scholars engaged in termite research, young researchers and students, as well as professionals from pest control industries. With PRTRG Conference, we continue providing the participants with a forum for the transfer of knowledge and future research collaboration through scientific and technical presentations.

The 14th PRTRG Conference Thailand is a historic and important event in PRTRG history. It is our first physical conference since the global outbreak of coronavirus (Covid-19). The pandemic hindered our initial plan to hold it last year (2022). But with the help and participation of our society members, friends, and colleagues, we manage to hold it in early March 2023.

This year, along with the established session of “Kunio Tsunoda Memorial Lecture”, we also present “Tsuyoshi Yoshimura Memorial Talk” as a special tribute session to honor and commemorate the long and hugely important contributions of the late Prof. Yoshimura to PRTRG (Secretary General of PRTRG 2004 – 2016). We also consistently provide travel fund awards (5 recipients) to support young scientists/students to take participation in the PRTRG conference and challenge themselves to learn and gain invaluable scientific experience.

Last but not least, I would like to thank the local organizers, Mr. Winyoo Jesadavisut (Chairman of the Organizing Committee) & his team, for their dedicated work to preparing the conference; Dr. S Khoirul Himmi (Secretary General of PRTRG) for preparing the program and proceedings; Thailand Pest Management Association (TPMA) and Kasetsart University for their support as co-organizers; and all sponsors for their financial support and participation.

I wish you all a successful and fruitful conference.

Suchart LEE

Su-Chart LEE
President of PRTRG 2020 – 2024

PRTRG Committee

Pro-Team Executive Committee

President	:	Mr. Su-Chart Leelayouthyotin (King Service Center, Thailand)
Secretary General	:	Dr. S Khoirul Himmi (National Research and Innovation Agency/BRIN, Indonesia)
Honorary Treasurer	:	Mr. Steph Chua Yang Peng (Bentz Jaz, Singapore)
Executive Committee Members	:	Prof. Dr. Chow-Yang Lee (University of California, Riverside, USA) Prof. Dr. Sulaeman Yusuf (National Research and Innovation Agency/BRIN, Indonesia) Prof. Dr. Dayu Zhang (Zhejiang A&F University, China) Prof. Dr. Hou-Feng Li (National Chung Hsing University, Taiwan) Dr. Eric Cheng Shing Kwong (Ridgid Plumbing Limited, Hong Kong) Dr. Veera Singham (Universiti Sains Malaysia, Malaysia) Dr. Partho Dhang (Urban Entomologist, Philippines)
Honorary Auditor	:	Dr. Chun-I Chiu (Chiang Mai University, Thailand) Dr. Rungarun Tisgratog (Kasetsart University, Thailand)

Proceedings Editor

Dr. Partho Dhang (Independent Consultant of Urban Pest Management, Philippines)
Dr. S Khoirul Himmi (National Research and Innovation Agency/BRIN, Indonesia)

The Organizing Committee of the 14th PRTRG Conference

Mr. Winyoo Jesadavisut (Chairman of Organizing Committee) – TPMA
Mr. Supanut Kiatyingpracha – President of TPMA
Mr. Surath Aebtarm – TPMA

Office

PRTRG Main Office

48 Toh Guan Road East, #06-139 Enterprise Hub Singapore 608586

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Country Representative

- China : Prof. Dr. Dayu Zhang (Zhejiang A&F University)
- Hong Kong : Dr. Cheng Shing Kwong (Ridgid Plumbing Limited)
- Indonesia : Prof. Dr. Sulaeman Yusuf (National Research and Innovation Agency/BRIN)
- Malaysia : Dr. Veera Singham (Universiti Sains Malaysia)
- Philippines : Dr. Partho Dhang (Urban Entomologist)
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Thailand is a country located in Southeast Asia, known for its rich culture and traditions. The geography of the country includes both tropical beaches and mountainous regions, providing a unique and diverse landscape. The country has a total area of approximately 513,120 square kilometers and a population of about 69 million people

Bangkok, also known as Krung Thep, is the capital and largest city of Thailand. It is situated on the banks of the Chao Phraya River and is home to more than 8 million people. Bangkok is renowned for its glittering temples, bustling street markets, and vibrant nightlife. The city is also famous for its street food and is a popular destination for tourists. Some of the most notable attractions in Bangkok include the Wat Arun (Temple of Dawn), the Wat Phra Kaew (Temple of the Emerald Buddha), and the Grand Palace. Despite its bustling atmosphere, Bangkok is also rich in cultural heritage, with a long history dating back to the 16th century when it was established as the capital of Thailand. Today, Bangkok is a hub of economic activity and is considered one of the most important cities in Southeast Asia.

Thailand has a tropical climate, with three distinct seasons: the hot season, the rainy season, and the cool season. The country is known for its rich culture and traditions, including the Buddhist religion, which is practiced by the majority of the population. Thailand is famous for its vibrant festivals and colorful ceremonies, such as the Songkran Festival, the Loi Krathong Festival, and the Vegetarian Festival.

Thai people are known for their hospitality and friendliness, making it a great place to visit and experience the local culture. Whether you're exploring the bustling streets of Bangkok or relaxing on a tropical beach, Thailand offers a truly unforgettable experience.

Venue & Transportation

Grand Ballroom Hall
S Ratchada Leisure Hotel, 2F

Address: 52 Tiamruammit Road,Ratchadapisek, Huaykwang, Bangkok, 10310 Thailand.
Contact Numbers: +66 (0) 2246 0795-6

Going to the S Ratchada Leisure Hotel is easy. Simply get off at one of the recommended MRT exits and call a taxi.

- **Thailand Cultural Center (MRT) Use Exit 4. This is the closest station from S Ratchada so expect to arrive at the hotel within 10 minutes.**
- **Rama 9 (MRT) Use Exit 1. This station is approximately 2 km from the hotel.**
- **Huay Kwang (MRT) Use Exit 2. This station is approximately 2.5 km from the hotel.**

Program at a Glance

Thursday | 2 March 2023

08:00 – 08:45	**Registration**
08:45 – 09:00	**Opening Ceremony**
	Welcome Speech – President of PRTRG, Mr. Su-Chart Lee
09:00 – 09:45	**Keynote Lecture**
	Dr. Chow-Yang Lee – University of California, Riverside, USA
09:45 – 10:00	**Photography Session**
10:00 – 10:15	**Tea Break**
10:15 – 11:45	**Kunio Tsunoda Memorial Lecture**
	Dr. Faith Oi – University of Florida, USA
	Dr. Partho Dhang – Urban Pest Management Expert, Philippines
	Dr. Amonrat Panthawong – Kasetsart University, Thailand
11:45 – 12:00	**The PRTRG Travel Fund Award Ceremony**
12:00 – 13:15	**Lunch Break**
13:15 – 14:30	**Tsuyoshi Yoshimura Memorial Talk**
	Dr. Kok-Boon Neoh – National Chung Hsing University, Taiwan
	Dr. S Khoirul Himmi – National Research and Innovation Agency, Indonesia
14:30 – 15:00	**Poster Presentation – Tea Break**
15:00 – 17:30	**Session for Oral Presentation**
17:30 – 17:45	**Closing of Day 1**
18:00 – 20:00	**Welcome Dinner**
	S Ratchada Leisure Hotel

Friday | 3 March 2023

08:00 – 08:30	**Registration**
08:30 – 09:30	**Session for Innovation in Termite Management**
	Dr. Sin-Ying Koou, Agnes –ENVU APAC, Singapore
	Dr. Hui-Siang Tee – SPS Product Biology Lead APAC Syngenta, Malaysia
09:30 – 10:00	**The next PRTRG 15 Conference Announcement**
	Tea Break and Preparation for the Excursion
10:00 – 18:00	**Excursion Program**
	Visiting Termite Trial Site at Ratchaburi Province
18:00 – 21:00	**Gala Dinner and Closing Ceremony**
	Viva Alangka Dinner Cruise, Bangkok

Excursion

Termite Trial Site plot at Ratchaburi Province



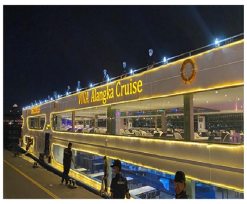


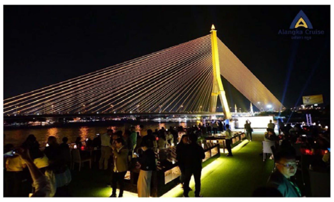

Gala Dinner

Viva Alangka Cruise

Experience the beautiful night sceneries of Chao Phraya River (Asiatique The Riverfront)

www.facebook.com/vivaalangka/



10:00	Departure from S Hotel to Ratchaburi Province
12:00	Lunch
13:30	Visit "Termite Trial Site"
14:30	Reforestation together at Termite Trial Site
15:00	Departure from Termite Trial Site
18:00	Arrive at Asiatique The Riverfront
19:30	Gala Dinner : Viva Alangka Cruise, Chao Phraya River
21:45	Arrive at Asiatique The Riverfront
22:00	Depart from Asiatique The River front to S hotel

Speakers

Keynote Lecture

Thursday | March 2, 2023 | Time: 09:00 – 09:45

Termite management in Southeast Asia – Present strategies and challenges

Prof. Dr. Chow-Yang Lee

University of California, Riverside, USA

Chow-Yang Lee is the Professor and Endowed Presidential Chair in Urban Entomology at the University of California, Riverside, USA. His research involves understanding behavioral, ecological, and physiological adaptations of insect pests in the urban environment. He has published over 270 peer-reviewed papers and books and mentored 16 Ph.D. and 32 M.S students. He is one of the co-editors of the books: Biology and Management of the German Cockroach (2021) and Advances in the Biology and Management of Modern Bed Bugs (2018). Chow-Yang received many awards at international and national levels, including the *Recognition Award in Medical, Urban and Veterinary Entomology (2022)* from the Entomological Society of America, *Arnold Mallis Distinguished Achievement Award in Urban Entomology (2022)* from the National Conference on Urban Entomology (USA), *2012 Top Research Scientists Malaysia*, *Fulbright Scholarship* (2002), and the *National Young Scientist Award Malaysia* (2000).

Kunio Tsunoda Memorial Lecture

Thursday | March 2, 2023 | Time: 10:15 – 10:45

Termite management in the United States – Present strategies and challenges

Faith M. Oi, Ph.D.

University of Florida, USA

Dr. Faith Oi is an urban entomologist and extension specialist. She is the Director of Pest Management University (https://pestmanagementuniversity.org/), an academy that provides state-of-the-art education and hands-on training for the industry. As a faculty member in the Entomology and Nematology Department at the University of Florida, USA, she works at a "grassroots-level" and does applied research to solve industry problems. She has published >250 extensions, refereed and technical journal articles, led the development of 10 multiday curricula in structural pest management, and has given >350 presentations. Her latest efforts also involve working with county faculty to direct market IPM to residents through existing programs. She received her Ph.D. from the University of Florida and her M.S. and B.A. degrees from the University of Hawai'i, Mānoa.

Kunio Tsunoda Memorial Lecture

Thursday | March 2, 2023 | Time: 10:45 – 11:15

Impact of climate change on bio-ecology of subterranean termite

Partho Dhang, Ph.D.

Urban Entomologist, Philippines

Partho Dhang received his B.S., M.S., and Ph.D. in zoology from University of Madras, Chennai India. After his doctorate, he joined a private organization, SPIC Science Foundation in India as a scientist and worked on the development of various bio-rational, crop protection products including plant-based bio-pesticides, insect pheromones, and microbial larvicides. Most of the products were commercialized during his tenure. He left India in the year 1998, to work for a number of companies on short stints, mainly focused on urban entomology. Prominent among them was a Singapore government-funded (EDB) project on urban pests. In 2005 he moved to Philippines to set up his own consultancy work.

His close association with the pest control industry, covering works such as research and development, training, and business development has allowed him to edit and write a number of books, all published by CABI. He is also a prolific speaker at international conferences across the world. He is a regular contributor of articles to various international magazines. Presently he serves on the panel of judges for the award of doctoral degree for two universities in India in the subject of economic entomology, and as a technical consultant for an international pest control magazine. He is also involved in the development of a number of pest control products, including termite bait and a sprayable bait for cockroach.

Kunio Tsunoda Memorial Lecture

Thursday | March 2, 2023 | Time: 11:15 – 11:45

Case studies of termite control in Thailand

Dr. Amonrat Panthawong

Kasetsart University, Thailand

Dr. Amonrat Panthawong is a lecturer at Department of Entomology, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand. Her research direction centers around the behavioral, ecological, and physiological adaptations of urban insect pests. She is also interested in the arthropods of zoonotic and propagule pressure in invasion history of veterinary concern. Her recent research activities focus on morphological and biological traits, insecticide resistance, and environmental physiology of termites and other urban insect pests. The research work started with reviews on termite species in Thailand from previous publications. Different methods of termite management were also considered. This valuable data will serve as essential information for her further research on termite management in the future.

Tsuyoshi Yoshimura Memorial Talk

Thursday | March 2, 2023 | Time: 13:30 – 14:00

Cadaver management in termites

Dr. Kok-Boon Neoh

National Chung Hsing University, Taiwan

Dr. Kok-Boon Neoh is an Associate Professor at the Department of Entomology, National Chung Hsing University, Taiwan. He received his Ph.D. degree from Universiti Sains Malaysia in 2010. He was a postdoctoral research fellow at Kyoto University, Japan, from 2012-2015 before he joins his current affiliation. His research primarily focuses on the ecology and pest management of urban pests, including mosquitos, cockroaches, ants, and rove beetles. To date, he published 50 peer-reviewed papers.

Tsuyoshi Yoshimura Memorial Talk

Thursday | March 2, 2023 | Time: 14:00 – 14:30

Nesting behavior of drywood termite – A key for integrated management

Dr. S Khoirul Himmi

National Research and Innovation Agency (BRIN), Indonesia

Dr. Himmi is a senior researcher at Research Center for Applied Zoology, National Research and Innovation Agency (BRIN), Indonesia. He earned his master and doctoral degree from Kyoto University, Japan. He received the HOPE Fellowship from the Japan Society for the Promotion of Science (JSPS) in 2016. Since 2017, he is actively involved as a Project Leader in the Japan-ASEAN Science Technology Innovation Platform (Working Package 3: Biodiversity and Bioresources), an international collaborative research program supported by the Japan Science and Technology Agency (JST). His research activities are mainly focused on bioecology and behavioral responses, physiology, and management of termites and wood-deteriorating organisms. Currently, he is serving as the Secretary-General of the Pacific-Rim Termite Research Group (PRTRG) 2020 – 2024.

Innovation in Termite Management

Friday | March 3, 2023 | Time: 08:30 – 08:45

Eliminating blindless in termite baiting system

Dr. Sin-Ying Koou, Agnes

2022 Environmental Science SG Pte. Ltd (ENVU), Singapore

Dr. Agnes Koou is the Solution Development Manager for Professional Pest Management and Vector Control for the APAC region in Envu. She is working closely with development specialists, university researchers, and technical experts for solutions development innovation and technologies. She has more than 10 years of experience in public health sector. She was a scientist at Environmental Health Institute, National Environment Agency, Singapore; and her past experience was in vector control research including insecticide resistance monitoring and management, and evaluation of insecticide products for use in operational vector control program in Singapore.

Innovation in Termite Management

Friday | March 3, 2023 | Time: 08:45 – 09:00

Chlorantraniliprole termiticide – Innovative Chemistry for Comprehensive Protection

Dr. Hui-Siang Tee

Syngenta Crop Protection Sdn. Bhd., Malaysia

Dr. Tee Hui Siang is SPS Lead, Product Biology APAC at Syngenta, Malaysia. He graduated with a Ph.D. specializing in Urban and Industrial Entomology from Universiti Sains Malaysia. He has published 8 research papers and 1 book chapter in entomological studies. His role includes R & D and portfolio development in professional pest management, ornamental, and turf.

Program Agenda

Program Agenda

Thursday | March 2, 2023	
08:00-08:45	Registration
08:45-09:00	Opening Ceremony Welcome Speech – President of PRTRG, Mr. Su-Chart Lee
Keynote Lecture	Moderator: Charunee Vongkaluang
09:00-09:45	**K_01 Termite management in Southeast Asia – Present strategies and challenges** Chow-Yang Lee
09:45-10:00	Photography Session
10:00-10:15	*Tea Break*
Kunio Tsunoda Memorial Lecture	Moderator: Hou-Feng Li
10:15-10:45	**K_02 Termite management in the United States – Present strategies and challenges** Faith M. Oi
10:45-11:15	**K_03 Impact of climate change on bio-ecology of subterranean termite** Partho Dhang
11:15-11:45	**K_04 Case studies of termite control in Thailand** Amonrat Panthawong
11:45-12:00	The PRTRG Travel Fund Award Ceremony
12:00-13:15	*Lunch*
Tsuyoshi Yoshimura Memorial Talk	Moderator: Chow-Yang Lee
13:20-13:30	A tribute to Prof. Tsuyoshi Yoshimura Chow-Yang Lee
13:30-14:00	**K_05 Cadaver management in termites** Kok-Boon Neoh
14:00-14:30	**K_06 Nesting behavior of drywood termite – A key for integrated management** S Khoirul Himmi
14:30-15:00	Poster Presentation – *Tea Break*
Oral Presentation **Section 1: Biodiversity, Ecology, and Systematics**	Moderator: Chun-I Chiu
15:00-15:15	**O_01 Addressing the gaps in termite taxonomy of India: Some case examples** Rituparna Sengupta, K. Rajmohana, and Jayati Basak

15:15-15:30	**O_02 Composition and distribution of termites (Isoptera) in Quang Nam, Vietnam** Nguyen Thi My, Nguyen Quoc Huy, Nguyen Van Quang, and Dang Ngoc Bich
15:30-15:45	**O_03 The desiccation tolerance of termite community in urban area** Chatchaton Wanthathaen, Chun-I Chiu, and Yuwatida Sripontan
15:45-16:00	**O_04 Non-mendelian families of Formosan subterranean termite found in Taiwan** Guan-Yu Chen and Hou-Feng Li

Oral Presentation

Section 2: Physiology, Morphology, and Structure Moderator: Dayu Zhang

16:00-16:15	**O_05 Anatomical structure of pronotum setae in the soldier of subterranean termites *Coptotermes* spp. (Blattodea: Rhinotermitidae)** Bramantyo Wikantyoso, Tomoya Imai, S Khoirul Himmi, Sulaeman Yusuf, and Wakako Ohmura
16:15-16:30	**O_06 Termite's elastic mandibles: Conceptual modeling for mechanics** Yi-Yu Wang, Tzu-Chia Liu, Chun-I Chiu, Kuan-Chih Kuan, Hou-Feng Li, and Kai-Jung Chi

Oral Presentation

Section 3: Management and Economic Impact Moderator: Sulaeman Yusuf

16:30-16:45	**O_07 Overview of termites damage to architectural works in Vietnam** Nguyen Quoc Huy, Nguyen Minh Duc, Nguyen Thuy Hien, and Le Quang Thinh
16:45-17:00	**O_08 Improved heat treatment to mitigate heat sinks for drywood termite (Blattodea: Kalotermitidae) management in condominiums** Jia-Wei Tay
17:00-17:15	**O_09 Long-term effects of baits on the foraging activity of a fungus-growing termite, *Odontotermes formosanus* (Blattodea: Termitidae)** Chia-Chien Wu, Chun-I Chiu, Wei-Ren Liang, Hsin-Ting Yeh, and Hou-Feng Li
17:15-17:30	**O_10 Laboratory trials for testing innovative anti-termite barriers: Assessment with different termite species** Marie-France Thévenon, Florent Chopinet, Jérôme Vuillemin, Hiroki Murotani, and Daouïa Messaoudi

17:30-17:45	Closing of Day 1
18:00-20:00	*Welcome Dinner* – S Ratchada Leisure Hotel

Program Agenda

Friday | March 3, 2023	
08:00-08:30	Registration
Session for Innovation in Termite Management	Moderator: Eric Cheng
08:30-08:45	**K_07 Eliminating blindless in termite baiting system** Sin-Ying Koou, Agnes
08:45-09:00	**K_08 Chlorantraniliprole termiticide – Innovative Chemistry for Comprehensive Protection** Hui-Siang Tee
09:00-09:15	**O_11 Features and applications of an automatic system for monitoring termite activity using DEKAN electromagnetic induction with non-looping method and LoRa communication** Junfeng Shen, Bosheng Chen, Xiaobin Shi, Xianhui Chen, Siwei Gao, Zheng Fang, Mei Zhang, and Dayu Zhang
09:15-09:30	**O_12 A novel wood preservative with vegetal extracts-cypermethrin combination for envelope treatment of wood against subterranean termites under H2-hazard class situations** Daouia Messaoudi, Andrew H.H. Wong, and Siti Hanim Sahari
09:30-09:45	The next PRTRG 15 Conference Announcement
09:45-10:00	*Tea Break* and Preparation for the Excursion
10:00-18:00	Excursion Program Visiting Termite Trial Site at Ratchaburi Province
18:00-21:00	*Gala Dinner and Closing Ceremony* Viva Alangka Dinner Cruise, Bangkok

List of Poster Presentations

14:30-15:00 | Thursday | March 2, 2023

P_01	**Biodiversity of termites in protected area at Chiang Mai University Hariphunchai Centre, Lamphun Province, Thailand** Sinsap Wongkoon, Chun-I Chiu, and Piyawan Suttiprapan
P_02	**Spatial understanding mediated by thigmotaxis in the soldier of subterranean termite *Coptotermes formosanus*** Bramantyo Wikantyoso, S Khoirul Himmi, Didi Tarmadi, Sulaeman Yusuf, and Wakako Ohmura
P_03	**Efficacy and versatility of a plant bio-based anti-termite product** Marie-France Thévenon, Florent Chopinet, Jérôme Vuillemin, Antoine Robert, Sophie Lafay, and Daouïa Messaoudi
P_04	**Termite survey on cultural heritage buildings: A case study in Central Java, Indonesia** Ikhsan Guswenrivo, Zulfah Laili, Nahar Cahyandaru, Henny Kusumawati, Sri Wahyuni, Al. Widyo Purwoko, Titik Kartika, Didi Tarmadi, S Khoirul Himmi, Sulaeman Yusuf
P_05	**The prospect of potential compounds from termite-fungi interaction for aggregation behavior of subterranean termite** Titik Kartika, Deni Zulfiana, Anis Sri Lestari, Ni Putu Ratna Ayu Krishanti, Anugerah Fajar, Sulaeman Yusuf, Didi Tarmadi, S Khoirul Himmi, Ikhsan Guswenrivo, and Nobuhiro Shimizu
P_06	**Fecal pellet dimension as a potential non-destructive species marker for cryptic drywood termite species** Anugerah Fajar, Bramantyo Wikantyoso, S Khoirul Himmi, and Sulaeman Yusuf
P_07	**Envelope wood protection against subterranean termites under H2-hazard class situations by a new generation wood preservative with vegetal extracts-cypermethrin components** Daouia Messaoudi and Andrew H.H. Wong
P_08	**A new generation bait matrix with vegetal extracts-diflubenzuron components, for the control of Asian subterranean termites *Coptotermes gestroi* (Blattodae: Rhinotermitidae) in Reunion Island** Florent Chopinet and Daouïa Messaoudi
P_09	**Efficacy performance of bio-based termiticide containing plant polyphenolic extracts from Berkem Biosolutions® against subterranean termites *Coptotermes gestroi* in soil treatment test** Daouïa Messaoudi, S Khoirul Himmi, Didi Tarmadi, Ikhsan Guswenrivo, and Sulaeman Yusuf

Proceedings

Abstract Book

Keynote and Invited Lectures

Thursday | March 2, 2023 | 09:00-09:45

K_01

Termite management in Southeast Asia – Present strategies and challenges

by

Chow-Yang Lee

Department of Entomology, University of California, Riverside, USA

Email: chowyang.lee@ucr.edu

Abstract

Termites are a major group of insect pests in Southeast Asia's urban areas. The tropical climate has endowed this region with an abundance of termite species. There are no invasive species that have been introduced to the region. *Coptotermes gestroi*, the most destructive species in buildings and structures, is considered native to the area. However, *C. gestroi* has become an invasive species in other parts of the world. It was introduced and established in new geographical regions such as the Marquesas Islands (Pacific Ocean), Mauritius and Reunion (Indian Ocean), Hawaii, South America (Brazil and Barbados), some West Indian islands, southern Mexico, the continental Southeast United States, Taiwan, and even Japan (Minami Torishima [Marcus Island]). Except for Northern Vietnam, the invasive *Coptotermes formosanus* is not found in Southeast Asia. *C. gestroi*'s range extends from Assam through Burma and Thailand to Malaysia and the Indonesian archipelago. This species was responsible for more than 85% of Malaysia's total building and structural damage. At the same time, they are ubiquitous in Thailand, Indonesia, and the Philippines, particularly in urban areas. Based on data gathered over the last 25 years, this species was discovered to be becoming increasingly important, displacing the distribution of *C. curvignathus* and *C. kalshoveni* in Malaysia. A similar situation has been observed in Indonesia, where *C. gestroi* is now more common in urban areas than *C. curvignathus*, which was previously thought to be widespread.

In addition to *C. gestroi*, several termite pest species coexist and infest buildings and structures. In Malaysia, other species include *C. curvignathus*, *C. kalshoveni*, *Microcerotermes crassus*, *Macrotermes gilvus*, *Macrotermes carbonarius*, *Odonototermes* spp., *Schedorhinotermes* spp., and *Ancistrotermes pakistanicus* can be found in and around buildings and structures. *Cryptotermes cynocephalus* is the most common drywood termite in Malaysia and Indonesia. *Microcerotermes crassus* is slowly becoming an important pest species in buildings and structures built on former rice fields in Thailand's suburbs. *M. gilvus*, *Microcerotermes losbanosensis*, and *Nasutitermes luzonicus* were the most common after C. gestroi in the Philippines. *Cryptotermes thailandis* is a drywood termite occasionally found in wooden houses and furniture, primarily in the southern part of the country, both inland and along the coast or on the islands. *Cryptotermes dudleyi* is the most important drywood termite species in the Philippines.

Pre-construction and post-construction management strategies against subterranean termites are currently used in Southeast Asia. Soil treatment with liquid termiticides and installing physical barriers are two pre-construction strategies. A pest management company can use several methods for post-construction treatment, including spot treatment, corrective soil treatment, and baiting. Insecticidal dust is blown into the mud tubes to treat spots. This is a symptomatic treatment that usually only lasts a few months. Baiting is a passive management technique in which termites consume baits containing a chitin synthesis inhibitor. This method has the potential to either suppress or eliminate the entire termite colony. Though it may take one to three months for the termite colony to be suppressed or eliminated, this method is popular because it uses fewer insecticides and is less intrusive than corrective soil treatment, which requires drilling the floor to

inject a relatively more significant amount of termiticides into the ground. Termite baits are also available in above-ground formulations that can be applied directly to active termite mud tubes.

Although baits were discovered to be highly effective, it is important to note that they are only effective against lower termites of the *Coptotermes* and *Schedorhinotermes* genera (family Rhinotermitidae). Baits typically perform moderately to poorly against higher termites. Because there is a broader range of pest termite genera in Southeast Asia and Australasia, including both lower and higher termites, such a situation may challenge pest management professionals because baiting only works against certain species. When multiple species attacked a structure simultaneously or in succession, the situation became even more complicated. Furthermore, when baiting reduces or eliminates populations of lower termites like *Coptotermes*, other secondary or non-pest species might become important and enter buildings. The re-infestation of a higher termite species after the suppression or elimination of lower termites is a major challenge in managing multi-genera termite faunas in Malaysia and Singapore, particularly with termite baits. It is currently impossible to manage higher termites effectively with baits.

Climate change will impact termite distribution in several ways. Buczkowski & Bertelsmeier (2016) predicted that out of 13 highly invasive termite species, 12 species are expected to increase in their global distribution significantly. Some parts of the continents will have suitable environmental conditions for >4 species simultaneously. Next, higher rainfall and flooding, especially those that we have experienced in Southeast Asia, may increase the rate of degradation of termiticides. The warmer soil temperature and higher moisture enhance termiticide degradation by microorganisms. Warmer and moist soil conditions contribute towards greater desorption and significant volatilization losses. Increased rainfalls also cause the leaching of some termiticides (especially neonicotinoids).

Thursday | March 2, 2023 | 10:15-10:45

K_02

Termite management in the United States – Present strategies and challenges

by

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Abstract

There are approximately 45 species of termites in the United States. Florida has the highest number of termite species of any state (N=~20), including 6 invasive species that are established. There is no federally mandated surveillance for pests infesting structures; however, interceptions are recorded by the United States Department of Agriculture. By analyzing almost 100 years of records, Blumenfeld and Vargo (2020) identified 906 non-native termite interceptions in 29 different states. States with the highest number of interceptions include Florida (232), New York (104), California (95), Louisiana (82), and Texas (70). Non-native interceptions included invasive species established in the U.S., such as *Coptotermes formosanus, C. gestroi, Cryptotermes brevis,* and *Nasutitermes corniger*, and those that are not currently established (*N. ephratae, K. flavicollis, N. nigriceps*) but have "invader traits."

The absence of any surveillance system in the U.S. for structural pests combined with proof that interceptions of potentially destructive termite species occur provides a strong rationale for effective control methods. Product efficacy depends on the 1) inherent properties of the product, 2) built environment, and 3) competency of the applicator. Soil termiticides, baits, wood treatments, and physical barriers can claim structural protection depending on the product and application technique. Products that are pesticides and claim structural protection must meet federal performance standards. However, these performance standards can vary, providing implementation and training challenges for the professional pest control industry and leaving consumers confused. No regulatory agency is responsible for setting performance standards or enforcement for physical barriers. At least one manufacturer of physical barriers has requested a federal review of their product but has not been successful because they are not a pesticide.

Another challenge to termite management and control is working across another industry: building construction. Understanding the built environment, meeting various building code requirements for termite protection, cooperating with building contractors, and meeting construction schedules are difficult. There are two times when a structure can be protected: 1) during construction, also known as "pre-construction" or the "new construction" phase; 2) post-construction. Building contractors are most involved during the "new construction" phase. The most effective control for the construction type and termite species in the area may not be selected due to scheduling and economic factors. Property owners are most engaged during the post-construction phase. When treatments fail, it is not uncommon for pest control companies to end up in litigation. While most disputes are confidentially settled, high-profile and public lawsuits can damage a company's reputation. Each side can hire expert witnesses and use research data to support their case.

There are hundreds of excellent research publications on termite biology, control, and product efficacy, but the applicator is essential in effective termite management and control. The applicator is often charged with termite identification, doing structural inspections that require knowledge of termite biology and behavior, and applying products according to label guidance, which often includes calculations to determine

soil termiticide quantities based on building construction. Some states do not require any testing or certification to become the applicator for termite control products.

Finding and maintaining a well-trained workforce and keeping up with changes in termite species distributions, building construction materials and methods, products, and regulations will be continuous. How we respond to these challenges will make the difference in the level of success for termite management and control.

Thursday | March 2, 2023 | 10:45-11:15

K_03

Impact of climate change on bio-ecology of subterranean termite

by

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Abstract

The interaction of termites and humans possibly started when termites attacked crops and manmade structures containing cellulosic material. This interaction has now taken a shape resembling a confrontation, thanks to extensive land use by humans for agriculture and development. Urbanization is playing a big role; wherein prime areas of the earth's landmass are rapidly being converted into real estates. Trade in wood and wood-derived products also play a role in transporting infestation across the globe. In this manner, invasive termite species have found new shelters in territories where they were previously unknown. The number of invasive termites has jumped from 17 to 28 in little over half a century. In this situation, it is important to know if climate change, a limiting factor in termite bio-ecology will play any role in making them a renewed concern.

In fact, research is showing that climate is creating possibilities of changes in the bio-ecology of termites across the globe. This change is being felt differently in different regions. While changes in swarming times are observed Northern hemisphere, the tropic is encountering more life-history related changes. Another unique phenomenon noted as a result of climate change is hybridization among invasive termite species. It is being noted that two invasive species namely *C. formosanus* and *C. gestroi*, are hybridizing and producing hybrid colonies with twice the growth rate of incipient conspecific colonies in parts of Florida. This is happening as the dispersal flight season of the two species has begun to overlap due to changes in local climate. Mating pairs of heterospecific individuals were observed in the field with *C. gestroi* males preferentially engaging in mating behavior with *C. formosanus* females.

One area where termite and climate change need a scrutiny is with regard to methane production. Termites are known to produce 1-3% of global methane, and methane being a greenhouse gas is responsible for climate change. This aspect of termite-derived methane production is supplemented by a new finding in a recent publication where researchers using field measurements, show that termite mounds in fact oxidize, on average, half of the methane produced before emission.

Termite posing newer threat induced by climate change will be eventually dependent on human activities. Continue to transport infested wood, faulty construction, using untreated wood, using chemical barriers as protection will be the reasons for new infestation to surface. Protecting service wood, enforcing sanitary requirements, policing imports and eliminating colony by baits will be necessary to keep future check in place.

Thursday | March 2, 2023 | 11:15-11:45

K_04

Case studies of termite control in Thailand

by

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Abstract

Termites are the most damaging insects of wood that can cause about 40 billion dollars in global economic losses per year. While in Thailand, the economic damage caused by termites is about 1.5 billion dollars per year. Termite management planning is extremely important. Therefore, reviewing the case studies before planning is necessary. There have been extensive studies on termite control in Thailand consisting of chemical and non-chemical uses. For non-chemical termite control methods, many studies report on the effectiveness of using materials such as aluminum sheets, corals, and crushed glass to use as a barrier to prevent termites from entering the building. There are also reports of eradicating termite reproductive castes or eliminating nests to control the termite population as well. Some kinds of biological agents use entomopathogenic nematodes, entomopathogenic fungi, and predators are also included for biological control. For the chemical control method, some case studies reported on commonly used termiticides including fipronil, imidacloprid, chlorfenapyr, fenoxycarb, and fenvalerate. And common techniques for using termiticides consist of spraying the wood and soil surface, compressing chemicals into the timber, and pouring them on the ground. In addition, insect growth regulators such as hexaflumuron and triflumuron can be used as effective baits in toxic bait systems. Several studies demonstrated that butylene oxide, triethylamine, chromate copper arsenate (CCA), and disodium octaborate tetrahydrate (DOT) are used to preserve the woods by protecting against decay fungi and termites. These case studies show the efficacy, plus the pros and cons of different termite control methods, providing a very useful baseline for planning a termite control plan. However, there are still very few studies on termite prevention and management methods in Thailand. Therefore, it is necessary to further study this issue in the future.

Thursday | March 2, 2023 | 13:30-14:00

K_05

Cadaver management in termites

by

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Abstract

Termites were known to avoid contacting with dead termites that were killed by a slow-acting insecticide by sealing off the tunnel that provided access to the treated zone. Since then, researchers have believed that termites are necrophobic in nature. However, conflicting evidences exist. Termites use many sophisticated behaviors when they encounter cadavers in their nest. Undertaking behavior is a significant adaptation to social life in enclosed nests. Workers are known to handle, feed, and/or remove dead colony members from the nest. Such behavior prevents the spread of pathogens that may be detrimental to a colony. The study was first conducted in Kyoto University in 2010 when I was a visiting researcher under the supervision of the late Prof. Kunio Tsunoda and the late Prof. Tsuyoshi Yoshimura. We tested the responses to cadavers of four species from different subterranean termite taxa: *Coptotermes formosanus* Shiraki and *Reticulitermes speratus* (Kolbe) (lower termites) and *Microcerotermes crassus* Snyder and *Globitermes sulphureus* Haviland (higher termites). We also used different types of cadavers (freshly killed, 1-, 3-, and 7-day-old, and oven-killed cadavers) and mutilated nestmates to investigate whether the termites exhibited any behavioral responses that were specific to cadavers in certain conditions. Some behavioral responses were performed specifically on certain types of cadavers or mutilated termites. *C. formosanus* and *R. speratus* exhibited the following behaviors: (1) the frequency and time spent in antennating, grooming, and cadaver removal of freshly killed, 1-day old, and oven-killed cadavers were high, but these behaviors decreased as the cadavers aged; (2) the termites repeatedly crawled under the aging cadaver piles; and (3) only newly dead termites were consumed as a food source. In contrast, *M. crassus* and *G. sulphureus* workers performed relatively few behavioral acts. Our results cast a new light on the previous notion that termites are necrophobic in nature. The behavioral response towards cadavers depends largely on the nature of the cadavers and termite species, and the response is more complex than was previously thought. Such behavioral responses likely are associated with the threat posed to the colony by the cadavers and the feeding habits and nesting ecology of a given species.

Thursday | March 2, 2023 | 14:00-14:30

K_06

Nesting behavior of drywood termite – A key for integrated management

by

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Abstract

Rapid urbanization and global trade of woods and lignocellulosic-based materials have led to an increased number of invasive and economically-important termites. Of the 28 global-invasive termite species listed in a comprehensive review by Evans et al. (2013), eight species are drywood termites and their economic impacts have been estimated to account for ≈20% of the worldwide annual costs for termite control (est. US$40 billion in 2010) (Rust and Su, 2012). Drywood termites' behavior and social organization differ from their subterranean or mound-building relatives. They can infest timber and furniture without any need to contact with the ground to obtain moisture and have high resilience to adapt to low-moisture conditions for lengthy periods. Furthermore, the small size of their colonies frequently results in an entire colony being transported in a single, even small wooden material, and therefore, drives to the increase of drywood termite invasiveness.

The past practices in controlling drywood termites have been emphasizing the extensive use of pesticides. However, to have successful control, we need to overcome major obstacles/difficulties in detecting and locating the real-time presence of drywood termites, since the entire colony is living within a piece of wood. Technological breakthroughs have come slowly, with currently available tools ranging from acoustics, infrared, microwaves, to x-rays. Each of these detection tools, however, has its limitations/disadvantages and is more an aid in problem-solving rather than a definitive solution. Management options for controlling drywood termite infestations are typically placed into two broad categories: remedial or preventative, with further divisions into local (spot treatments) or whole-structure approaches (Lewis and Forschler, 2014). To achieve satisfactory eradication results in drywood termite control, the prevention and management strategies must look into more comprehensive approaches by integrating wood science and urban entomology (Yoshimura, 2011). One of the keys to integrated management of drywood termites may come from a better understanding of their nesting behavior.

Friday | March 3, 2023 | 08:30-08:45

K_07

Eliminating blindless in termite baiting system

by

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Abstract

Termite bait system has been invented and in the market for almost three decades. Since its inception, there has been little to no change in terms of its design or technology. With various technological advancements, we are exploring ideas to further improve this termite management technology. The effectiveness of baiting system is often dependent on various factors impacting the system, which we would like to discuss and invite participation in further advancing this termite management system.

Friday | March 3, 2023 | 08:45-09:00

K_08

Chlorantraniliprole termiticide – Innovative chemistry for comprehensive protection

by

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Abstract

Chlorantraniliprole is a non-repellent termiticide that provides excellent control of termites without harming beneficial insects. It is in a class of chemistry with a mode of action like no other termite control product. Laboratory and field studies showed that chlorantraniliprole is an innovative chemistry that provides effective termite control through feeding-cessation, aggregation effect, horizontal transfer effect, excellent soil binding properties, long-term field efficacy, and excellent environment and safety profile.

Feeding cessation and horizontal transmission test
Studies have proven chlorantraniliprole is highly effective against termites and halts termite feeding within hours of exposure. Once affected by chlorantraniliprole, termites began to exhibit increased aggregation and contact with other healthy colony members for hours. Affected termite became more lethargic and showed signs of muscle paralysis and decreased coordination, and termites died within several days after exposure.

5-year field residual test
In a modified U.S Forest Service concrete slab field trial in Bradenton, Florida, residues of chlorantraniliprole remained significantly higher than other termiticides, with 57% of the original amount if active ingredient remaining even after 5 years. This indicates that chlorantraniliprole provides long-term protection of buildings against termite attack.

9-year USDA-Forest Service Efficacy Test
In the USDA-Forest Service concrete slab test, chlorantraniliprole termiticide has demonstrated excellent performance up to 9 years of protection.

Excellent environmental profile
Chlorantraniliprole termiticide was registered for use on termites by the U.S EPA under its Reduced Risk Pesticide Program in 2010. In Singapore, it is also certified with leader 4 ticks in Singapore Green Building Product (SGBP) Certification Scheme.

Conclusion
Chlorantraniliprole termiticide brings innovation in liquid termiticide chemistry. Its non-repellent chemistry is indiscernible to termites. Termites exposed to chlorantraniliprole were found to halt feeding within hours of exposure, increase aggregation and translocate the chemistry throughout the colony, and termite mortality occurred within several days of exposure. Field efficacy trials demonstrated that chlorantraniliprole achieved excellent residuality in soil and provided effective long-term control up to 9 years.

Oral Presentation

Thursday | March 2, 2023 | 15:00-15:15

O_01

Addressing the gaps in termite taxonomy of India: Some case examples

by

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Abstract

Termite taxonomy in India demands revisionary studies and species redescriptions in order to keep pace with the recent advancements globally. The present study substantiates these facts quoting instances through six species of two frequently encountered genera namely *Coptotermes* Wasmann and *Odontotermes* Holmgren. The current gaps in their descriptive morphology are stated and a few additional morphometric traits have been suggested. Further, a few traits that are significant in distinguishing these species are highlighted. Advocating the benefits of an integrative approach, a total of eight 16S rRrna sequences were generated as a part of this study, through which two species namely *Coptotermes ceylonicus* Holmgren and *Odontotermes guptai* Roonwal and Bose receive their first ever molecular signatures.

Key words: Termite, *Coptotermes, Odontotermes,* 16S rRrna, morphometric traits, revision

Introduction

Termites, apart from their immense ecological role as ecosystem engineers, are of much economic importance in tropical and subtropical regions. They inflict severe damage to plantations, forest trees, and structural components in buildings, infiltrating even urban areas (Abe et al. 1991, Krishna et al. 2013). Though 12.34% of the total species cause severe damage, only 3.5% of the total termites globally are considered as significant pests. Species taxonomy in termites relies largely on the morphological characteristics of the soldier caste (Wikantyoso et al. 2021). Several termite researches globally are focused on the highly diverse pest categories (Bourguignon et al. 2016, Krishna et al. 2013). However, there are issues in studying termites due to lack of adequate taxonomic knowledge, ambiguous terminologies in species descriptions, high intra-specific variations, difficulties in characterizing some morphometric traits, inadequate images and also lack of genetic information in the GenBank (Korb et al. 2019, Wikantyoso et al. 2021, Kalleswaraswamy 2022). Minor taxonomic characters sometimes differ within pest and non-pest species rendering it difficult to distinguish morphologically closely related species (Gordh and Beardsley 1999). Several species are described even without the minimum morphological traits (Korb et al. 2019). In such cases adding a few morphometrics can help in achieving better accuracy in identification. This paper addresses a few issues in identification of six morphologically similar species under two genera *Coptotermes* Wasmann, 1896 (Rhinotermitidae) and *Odontotermes* Holmgren, 1910 (Termitidae), most of which are pest species. The study serves as a pointer demanding the need for species redescriptions and revisionsary studies in termite taxonomy of India. Contributing to the genetic diversity, a total of eight 16S rRrna sequences are added, through which *Coptotermes ceylonicus* Holmgren and *Odontotermes guptai* Roonwal and Bose receive their first ever molecular signatures.

Materials and methods

Morphological study: Being morphologically very similar the following three pairs of species have been selected for the study: 1. ***Coptotermes ceylonicus*** Holmgren, 1911 and–***Coptotermes heimi*** (Wasmann, 1902) (family Rhinotermitidae) 2. ***Odontotermes bellahunisensis*** Holmgren and Holmgren, 1917 and

Odontotermes guptai Roonwal and Bose, 1961 (Family Termitidae) 3. ***Odontotermes feae*** (Wasmann, 1896) and ***Odontotermes horni*** (Wasmann, 1902) (Family Termitiae).These species are frequently encountered in India, yet difficult to tell apart based on the existing taxonomic descriptions and keys. For each species, 10 specimens of the soldier caste from 10 colonies collected from 10 localities were morphologically studied. The study made use of the National Zoological Collections at Zoological Survey of India (ZSI), Kolkata. Species identification followed Chhotani 1997 and also based on a few additional traits as listed in table 1(A-C). The specimens were measured in alcohol for the selected attributes using Leica EZ4HD stereomicroscope (8-3.5X). For photography, LeicaA205 stereozoom microscope fitted with DFC 500 camera was used.

- Values revised in the present study (Table 1B) and
- * Significant traits that can be used for species differentiation (Table 1A, 1B, 1C)

For molecular studies the mitochondrial gene 16S rRrna, was sequenced for all the 6 species following Sengupta et al., 2022.

Results and discussion

A. Morphological studies:

1. *Coptotermes ceylonicus* Holmgren, 1911 and *Coptotermes heimi* (Wasmann, 1902) :

Gaps in the current descriptive morphology of *C. ceylonicus* and *C. heimi*:

- Head width/Head length index not available for *C. ceylonicus*.
- Range for left mandibular length not given for *C. ceylonicus*.
- Postmentum length unknown for *C. heimi.*

Table 1A. Additional morphometric traits proposed

Morphological traits	*C. ceylonicus* (Fig. 1)	*C. heimi* (Fig. 2)
Hind tibia length* (Scheffrahn et al. 2015)	0.85-1.00	0.95-1.10
Antennal faveolar distance* (Lee et al. 2017)	0.75-0.85	0.80-0.95
Right mandible length* (Lee et al., 2017)	0.75-0.90	0.85-1.00
Height of fontanelle base (Scheffrahn et al. 2015)	0.35-0.50	0.40-0.50
Head width/ Head length (Roonwal and Chhotani 1989)	0.81-0.95	0.77-1.04 (Chhotani, 1997
Left mandible length (Roonwal and Chhotani 1989)	0.65-0.85	0.70-1.00 (Chhotani, 1997)
Postmentum Length (Chhotani 1989)	0.85-1.00 (Chhotani, 1997)	0.80-1.00

2. *Odontotermes bellahunisensis* Holmgren and Holmgren, 1917 and *Odontotermes guptai* Roonwal and Bose, 1961:

Gaps in the current descriptive morphology of *O. bellahunisensis* and *O. guptai*:

- Total body length range was not known for *Odontotermes guptai*.
- Postmentum length in *Odontotermes guptai* was described with unusually small range (0.45-0.65 mm) whereas postmentum width of *O. bellahunisensis* was described with rather a bigger/larger range(0.70-0.90 mm)(Chhotani, 1997).
- Redescription of *O. bellahunisensis* by Vidyashree et al., 2018, is data deficient.
- Position of right mandibular tooth differ between these two species as per descriptions in Chhotani, 1997. But not a single measurement or index is available for characterization of the right mandible.

Table 1B. Additional morphometric traits proposed

Traits	*O.guptai* (Fig. 4)	*O.bellahunisensis* (Fig. 3)
Head thickness (lesser) (Josens and Deligne 2019)	0.55-0.78	0.66-0.80
Mandible length/Minimum head width (Sands 1992)	0.92-1.20	0.86-1.26
Left hind tibia length* (Josens and Deligne 2019)	0.95-1.35	0.80-1.15
Right mandibular tooth distance (Present study)	0.20-0.40	0.25-0.35
Right mandible length* (Present study)	0.55-0.95	0.75-0.90
Right mandibular tooth index* (Present study)	0.33-0.44	0.33-0.40
Total body length (Chhotani, 1997)	3.2-5.65	3.60-5.60 (Vidyashree et al., 2018)
Postmentum length (Maximum length) (Chhotani, 1997)	0.60-1.00	0.75-0.95
Postmentum width (Chhotani, 1997)	0.40-0.55	0.40-0.50

3. *Odontotermes feae* (Wasmann, 1896) and *Odontotermes horni* (Wasmann, 1902)*:*

Gaps in the current descriptive morphology of *O. feae* and *O. horni*:

- Left mandibular tooth distance, an important character in identifying the species of *Odontotermes* (Chhotani 1997, Saha et al. 2016), is not known for *Odontotermes feae*.
- Labrum characters of *O. feae* in existing description creates confusion in identification (Chhotani, 1997, Vidyashree et al., 2018). Matter is elaborated in 'Remarks'.
- Currently these two species can be distinguished only with tooth index character (Tooth distance from tip/Mandible length). The range is 0.50-0.55 for *O. feae* and 0.55-0.63 for *O. horni* (Chhotani 1997). As the ranges are very adjacent, a small error in measurement can lead to misidentification unless other differences are observed.

Table 1C. Additional morphometric traits proposed:

Traits	*O. feae* (Fig. 5)	*O. horni* (Fig. 6)
Head thickness (lesser)	1.25-1.75	1.20-1.55
Left hind tibia length*	1.95-2.30	1.70-2.15
Mandible length/Minimum head width*	0.80-1.13	0.96-1.35
Gulamentum width (Maximum)	0.70-1.05	0.65-0.90
Gulamentum length (Maximum)	0.50-0.65	0.45-0.60
Right mandible length	1.40-1.70	1.25-1.65
Left mandibular tooth distance*	0.60-0.80	0.70-1.00 (Chhotani, 1997)

Remarks: Though there is a little overlapping range, still a good difference is observed in the range of hind tibia length and length of both the mandibles in *Coptotermes* group. Infact, hind tibia length is observed to vary significantly in *Odontotermes* group also. Right mandibles have been characterized in pair 2 with measurement of its length and tooth index. Both can are potent characters in identifying species. Variation in postmentum shape is observed in *O. bellahunisensis,* though no significant differences in gulamentum shape and size are observed. In *O. feae,* labrum varies from blunt to point tipped in contrast to only pointed tip described in existing descriptions. Moreover, the shape is observed as either triangular or tongue shaped. Hence, labrum character should not be considered in distinguishing species of this group.

B. Molecular study: Accession numbers of generated 16S rRNA sequences of all the species are provided in Table 2.

Discussion

Though morphometrics are important in species taxonomy in termites and are considered as key characters (Maiti 2006, Wikantyoso et al. 2021), there are many gaps persisting in morphometric knowledge of Indian Isoptera species. Complexity in identification persists in the most widely distributed genera like *Odontotermes* and *Coptotermes* which need immediate attention. Infact, taxonomic validity of many species of Isoptera are still doubtful. Chouvence et al. 2016 pointed out needs for intensive revisionary studies on Genus *Coptotermes* from China along with accurate determination of synonyms for a few species. Though gut morphology of the workers are widely used in the species taxonomy of soil feeding termites (Donovan 2002), those are yet to be incorporated in most of the species descriptions in India. Such issues can be resolved only through species redesrciptions/ revisions. In addition, initiative is to be taken for identifying the imago castes for which molecular identification approach can be depended upon. Currently, for several species, worker castes and imagoes if collected alone cannot be identified up to species due to extremely scanty genetic information available for Indian termites in GenBank. Kalleswaraswamy, 2022 has thrown light on the dare need of barcoding the known termite species. At least adding one marker gene sequence to new morphological descriptions can help in refining accuracy in species taxonomy (Korb et al. 2019). Of more than 300 species of termites kown from India, only 70 spp. have molecular signatures (Kalleswaraswamy, 2022). Vidyashree et al., 2018 corroborates the use of 16S rRNA sequence as a good marker gene, hence the current study also sequenced the same gene.

Table. 2. 16S rRNA sequences with Accession numbers

Name of Species	Locality	Accession No.	Remarks
C. ceylonicus	Kolkata, West Bengal, India		First molecular signature
C. heimi	Sagar Island, Sunderban, West Bengal, India		Additional sequence from India
	Habra, West Bengal, India		
O. bellahunisensis	Digha, West Bengal, India		Second molecular signature
O. guptai	Purulia, West Bengal, India		First molecular signature
O. feae	East Midnapore, West Bengal, India		Second molecular signature
	Habra, West Bengal, India		
O. horni	Jalpaiguri, West Bengal, India		Additional sequence from India

Conclusion

There is a need for taxonomic revisions and species redescriptions in the termite taxonomy of India. Molecular tools can help to overcome the challenges in identification of worker castes and the imagoes.

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O_02

Composition and distribution of termites (Isoptera) in Quang Nam

by

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Abstract

Termites (Isoptera) play an important role in ecosystem, however some species are serious economic pests. The study on termite species composition and distribution was conducted in Quang Nam. 95 species belonging to 30 genera, and 3 families were recorded (with 89 species, 28 genera were found in this research). One genus (*Sinonasutitermes* Li and Ping 1986), ten species are new records for termite fauna of Vietnam. Result on termite distribution in different habitats showed that the species number in the Secondary forest was the highest (70 species, acourting for 78.7%), followed by Primary forest (42 species, 47.2%), Plantaion (30 species, 33.7%), Mountain field (17 species, 19.1%), Dam (15 species, 16.9%), Resident area was the lowest (13 species, 14.6%). For distribution of termites in different altitudes, the highest species richness was found at altitudes above 700-1,000m (52 species, 58.0%), followed by the altitudinal range between 300-700m (51 species, 57.3%), below 300 m (44 species, 49.4%), above 1.000-1,500m (27 species, 30.0%) and the lowest species richness was found at altitudes above 1,500 m (9 species, 10.1%).

Key words: *composition, distribution, Quang Nam, termites.*

Introduction

Quang Nam is a province in the South - Central Coast region of Vietnam. The area has a diverse topography and a large forest area (with over 59,3% coverage)**Error! Reference source not found.**. Because of the geographical location, natural conditions and climate, Quang Nam has high biodiversity, which is a place of exchange between the flora of the North and the South of Vietnam. Many studies on biodiversity have been conducted in the province and many rare and valuable animals have been discovered in protected areas and special-use forests. In addition, Quang Nam is well-known for its famous cultural heritage sites, industrial parks, dams, and luxury resorts. However, Quang Nam is also facing with the protection of them from termite infestation.

So far, the research on termites in Quang Nam is quite limited. In 1997, Nguyen Tan Vuong recorded six species of termites belonging to the genus *Macrotermes* distributed in Quang Nam province, including: *M. gilvus, M. latignathus, M. measodensis, M. serrulatus, M. hienensis* và *M. annandalei*. In 2014, Trinh Van Hanh et al. recorded six species of termites belonging to three genera, three families in Nam Hai resort (Hoi An city, Quang Nam), in which *Coptotermes* is the main pest. During this time, Nguyen Quoc Huy et al. conducted research in 3 world cultural heritage sites including Hue Ancient Capital, Hoi An Ancient Town and My Son Sanctuary. Research results have identified five species of two genera (*Crypotermes, Coptotermes*), 2 families of termites in Hoi An ancient town and 16 species of eight genera, six subfamilies, three families in My Son sanctuary. In which, *Coptotermes* is the dominant variety in the number of samples as well as species in the ancient town of Hoi An and *Odontotermes* is the dominant in the My Son sanctuary. In 2017, Nguyen Quoc Huy recorded six species of termites in Hoi An (two species of the genus *Cryptotermes* genus and four species of the *Coptotermes* genus). Thus, a total of 26 species of 11 genera were recorded in Quang Nam. This shows that the research on termites in Quang Nam is low in quantity and only concentrated in a few relics, residential areas, coastal resorts. There is no data on termites in natural forest habitats. Therefore, in order to supplement biodiversity data, particularly data on composition, the distribution of termites for Quang Nam province, contribute to the conservation of relics, architectural works, dams from termites, research on composition and distribution of termites in Quang Nam was carried out.

Materials and methods

Study sites

The study was conducted from 2017 to 2020 and the locations of survey routes were shown in Fig. 1.

Fig 1 Location map of termite survey and sampling routes in Quang Nam

The handling, preservation and analysis of specimens were carried out at the laboratory of the Institute of Ecology and Works Protection in Hanoi, Vietnam.

Termite collection and Identification

Termite samples were collected by both quantitative and qualitative method. At each site, we conducted the sampling of 1 to 3 km transects followed method of Nguyen et al. (1976) [7]. The transects were placed through the following habitats: Primary Forest (PF), Secondary Forest (SF), Plantation (P), Mountain Field (MF), Dams (D) and Residental Areas (RA). The sampling techniques was carried out by using digging tools such as trowels and screwdrivers to collect termites in tree-trunks, rotten roots, dry branches, under rotten coverage and termite nests, etc. We collected all termite castes and paid special attention to the soldiers for further work of species identification. Specimens were stored in small test tubes containing 75% alcohol and were brought to the laboratory of the Institute of Ecology and Works Protection to analysis and storage.

Identification: The main tool used in identification is a Leca MZ6 binocular magnifying glasses. The soldiers and alates were observed and measured the indicators according to the instructions in the document of Roonwal (1970). Finally, base on the taxonomic literature to determine the species name. The classificational documents used are those of Ahmad (1958, 1965), Nguyen Duc Kham et al., Huang et al. (2000), Thapa (1982), Roonwal & Chhotani (1989), and Chhotani (1997).

Results and discussion

Composition of termites in Quang Nam

The analysis results of termite samples obtained in this study have recorded 89 species belonging to 28 genera of three families (Kalotermitidae, Rhinotermitidae and Termitidae), of which 69 species have been identified the Science names or scientific names, 20 species have been identified the genera (Table 1).

Table 1. Composition of termites in Quang Nam

No	Science name	No	Science name
	KALOTERMITIDAE Enderlein, 1909		TERMITINAE Sjostedt, 1926
	KALOTERMITINAE Froggatt,1896		***Microcerotermes* Silvestri, 1901***
	Glyptotermes* Froggatt, 1896	47	*Mic. bugnioni* Holmgren, 1911*
1	*G. coorgensis* (Holmgren & Holmgren, 1917)**	48	*Mic. fletcheri* (Holmgren & Holmgren, 1917)**
2	*G. fujianensis* Ping 1983**	49	*Mic. minor* Holmgren**

No	Science name	No	Science name
3	*Glyptotermes* sp.1		***Globitermes* Holmgren, 1912**
4	*Glyptotermes* sp.2	50	*G. sulphureus* Haviland, 1898
5	*Glyptotermes* sp.3		***Termes* Linnaeus, 1758***
	***Cryptotermes* Banks, 1906**	51	*T. propinquus* Holmgren, 1914*
6	*Cryptotermes domesticus* Haviland, 1898		***Pericapritermes* Silvestri, 1915***
	RHINOTERMITIDAE Light, 1896	52	*P. dunensis* (Roonwal & Sen-Sarma)**
	COPTOTERMITINAE Holmgren 1910	53	*P. latignathus* (Holmgren, 1914)*
	***Coptotermes* Wasmann.1896**	54	*P. nitobei* Shiraki, 1909*
7	*C. curvignathus* Holmgren, 1913*	55	*P. parasperious* Thapa, 1981*
8	*C. emersoni* Ahmad 1953	56	*P. semanangi* Holmgren, 1913*
9	*C. gestroi* (Wasmann, 1986)	57	*P. tetraphilus* (Silvestri, 1922)*
	HETEROTERMITINAE Froggatt, 1896		***Pseudocapritermes* Kemner, 1934***
	Heterotermes Froggatt, 1896	58	*Ps. albipennis* Tsai & Chen, 1963*
10	*Heterotermes* sp.1	59	*Ps. parasilvaticus* (Ahmad 1965)*
11	*Heterotermes* sp.2		***Sinocapritermes* Ping & Xu, 1986***
	***Reticulitermes* (Holmgren 1911)**	60	*S. mushae* (Oshima & Maki, 1977)*
12	*R. chinensis* Snyder, 1923*	61	*S. parvulus* (Yu & Ping)**
13	*R. flaviceps* (Oshima,1911)*	62	*S. vicinus* Xia et al., 1983**
14	*R. speratus* (Kolbe , 1885)*	63	*Sinocapritermes* sp.
15	*R. magdalenae* Silvestri, 1927*		***Mirocapritermes* Holmgren 1914**
	RHINOTERMITINAE Froggatt, 1896	64	*Mirocapritermes* sp.
	***Schedorhinotermes* Silvestri, 1909**		***Dicuspiditermes* Krishna,1965***
16	*S. brevilatus* (Haviland)*	65	*D. garthwaitei* Gardner, 1944*
17	*S. javanicus* Kemner, 1934	66	*Discuspiditermes* sp.1
18	*S. medioobscurus* Holmgren, 1914	67	*Discuspiditermes* sp.2
19	*S. rectangularis* Ahmad, 1965*		NASUTITERMITINAE Hare, 1937
20	*S. sarawakensis* (Holmgren, 1913)*		***Nasutitermes* Dudley, 1890**
21	*S. tarakaensis* Oshima 1914*	68	*N. mantagensis* (Haviland, 1898)*
22	*S. translucens* (Haviland, 1898)*	69	*N. mantagensiformis* (Holmgren, 1913)
	TERMITIDAE Westwood, 1840	70	*N. longinasoides* Thapa, 1981**
	Macrotermitinae Kemner, 1934	71	*N. ovaltus* Fan, 1983*
	***Ancistrotermes* Silvestri, 1912**	72	*Nasutitermes* sp.1
23	*Ancistrotermes pakistanicus* Ahmad, 1955	73	*Nasutitermes* sp.2
	***Macrotermes* Holmgren, 1909**	74	*Nasutitermes* sp.3
24	*M. annandalei* Silvestri, 1914		***Hospitalitermes* Holmgren, 1912***
25	*M. barneyi* Light, 1924*	75	*H. damenglongensis* He & Gao, 1984*
26	*M. beaufortensis* Thapa, 1981*	76	*H. jepsoni (*Snyder, 1934)*
27	*M. gilvus* (Hagen, 1858)	77	*H. medioflavus* (Holmgren, 1913)*
28	*M. latignathus* Thapa, 1981		***Lacessititermes* Holmgren, 1912***
29	*M. maesodensis* Ahmad, 1965	78	*L. albipes* (Haviland, 1898)*
30	*M. serrulatus* Snyder, 1934	79	*L. balavus* Kemmer, 1934*
31	*Macrotermes* sp.1		***Bulbitermes* Emerson, 1949***
32	*Macrotermes* sp.2	80	*B. laticephalus* Ahmad, 1965*
	***Odontotermes* Holmgren, 1912**	81	*Bulbitermes* sp.1
33	*O. angustignathus* Tsai & chen, 1963	82	*Bulbitermes* sp.2
34	*O. conignathus* Xia & Fan, 1982*		***Havilanditermes* Light, 1930***
35	*O. ceylonicus* Wasmann, 1902	83	*H. communis* Li & Xiao, 1989**
36	*O. feae* Wasmann, 1896		***Aciculioiditermes* Ahmad, 1968***
37	*O. formosanus* Shiraki,1909*	84	*Aciculioiditermes* sp.*
38	*O. hainanensis* Light, 1924		***Ahmaditermes* Akhtar, 1975***
39	*O. longignathus* Holmgren,1914*	85	*A. perisinuosus* Li & Xiao, 1989*
40	*O. maesodensis* Ahmad, 1965*	86	*A. tiantongensis* Ping & Xu 1993**
41	*O. proformonasus* Ahmad, 1965		***Sinonasutitermes* Li & Ping, 1986****
42	*O. pyriceps* Fan, 1985*	87	*Sinonasutitermes* sp.
43	*O. sarawakensis* Holmgren, 1913*		***Subulioiditermes* Ahmad, 1968***
44	*Odontotermes takensis* Ahmad, 1965*	88	*Subulioiditermes* sp.
45	*Odontotermes* sp.		***Pilotermes* He 1987***
	***Microtermes* Wasmann, 1902**	89	*Pilotermes jiangxiensis* He, 1987
46	*Mi. obesi* Holmgren, 1913		

Noted: (*): New species and genera recorded for the study area; (**): New species and genera recorded for Vietnam termite area;

In comparison with the list of termite species recorded in Vietnam, this study has added 10 new species (*Glyptotermes coorgensis*, *Glyptotermes fujianensis, Microcerotermes fletcheri*, *Microcerotermes minor*, *Pericapritermes dunensis*, *Sinocapritermes parvulus*, *Sinocapritermes vicinus, Nasutitermes longinasoides, Havilanditermes communis* và *Ahmaditermes tiantongensis*) and 2 genera (*Sinonasutitermes* và *Sinocapritermes*) for Vietnam termite fauna.

Previous studies have only focused on investigating termites in residential areas or monuments and the surrounding environment, so the number of species is low. Compared with the research results on termites in Quang Nam by Trinh Van Hanh et al (2014), Nguyen Quoc Huy et al (2014), Nguyen Quoc Huy (2017) và Nguyen Tan Vuong (1997), this study recorded 49 additional species (not including sp.) and 19 genera for the study area. However, six species (*Neotermes koshunensis, Coptotermes ceylonicus, C. formosanus, Hypotermes makhamensis, H. sumatrensis and Macrotermes hienensis*) and two genera (*Neotermes* and *Hypotermes*) were previously recorded but not found in the study area. Thus, a total of 95 species belonging to 30 genera, three families were recorded for termites area, this is the first comprehensive study on termite species composition for Quang Nam province.

Distribution of termites in the studied habitat

Habitat directly or indirectly affects the ability of nest creating, foraging food as well as other activities of termites. In this study, the distribution of termites was analyzed according to six main habitats. The results showed that the largest number of species was found in SF habitat (70 species, accounting for 78.7% of the total number of species collected in the study area), followed by PF (42 species, accounting for 47.2%), P (30 species, accounting for 33.7%), MF (17 species, accounting for 19.1%), D (15 species, accounting for 16.9%), the smallest number of species was found in RA habitat (13 species, accounting for 14.6%) (Table 2).

Table 2. Species number of termite subfamilies was found in six habitats in Quang Nam

Science name	PF		SF		P		MF		D		RA	
	N	P	N	P	N	P	N	P	N	P	N	P
Kalotermitinae	4	4.5	4	4.5	0	0.0	0	0.0	0	0.0	1	1.1
Coptotermitinae	1	1.1	2	2.2	2	2.2	1	1.1	1	1.1	2	2.2
Heterotermitinae	6	6.7	5	5.6	0	0.0	0	0.0	0	0.0	0	0.0
Rhinotermitinae	1	1.1	7	7.9	4	4.5	1	1.1	1	1.1	1	1.1
Macrotermitinae	8	9.0	19	21.3	14	15.7	8	9.0	9	10.1	6	6.7
Termitinae	12	13.5	14	15.7	9	10.1	6	6.7	4	4.5	2	2.2
Nasutitermitinae	10	11.2	19	21.3	1	1.1	1	1.1	0	0.0	1	1.1
Total	**42**	**47.2**	**70**	**78.7**	**30**	**33.7**	**17**	**19.1**	**15**	**16.9**	**13**	**14.6**

Noted: PF: Primary forest; SF: Secondary forest; P: Plantation; MF: Mountain field; D: Dams; RA: Residental area; N: number of species; P: percentage.

The results showed that there is not only the diffirence between habitats in the number of species but also in termite species composition. The results in Table 2 showed that all seven subfamilies which was obtained in the study area were found in the PF and SF habitats and the lower number of subfamilies was found in the rest habitats, from 4 to 6 subfamilies for each habitat. Besides, the results also showed that the dominance of each subfamily is different in each habitat. Subfamily of Macrotermitinae are present in all studied habitats and account for the highest proportion in most habitats heavily influenced by humans. In PF habitat, the number of species belonging to this subfamily is lower than Nasutitermitinae and Termitinae. The two subfamilies Termitinae and Nasutitermitinae accounted for a high proportion of species in the PF and SF habitats, but very low rates in the P, MF, and RA habitats and no species of the subfamily Nasutitermitinae were found in the P, MF, and RA habitats.

Based on the type of food used and their nest structure, that can partly explain the above difference. According to Jone and Eggleton (2010), the fungus – growing termites, Macrotermitinae could forage a wide range of food sources (group II) such as wood, grass, leaf-litters and micro-epiphytes. Termitinae are group III that feed on highly decayed wood that lost its structure and become friable and soil-like. Nasutitermitinae included species of group II, group III and group IV (soil feeders with a low organic). The nests of Macrotermitinae could be above ground or underneath with stable and sophisticate structure, which are highly capable of adapting to almost all habitats. Nests of group III and IV termites are often simple structure in decay wood or humus layer on ground surface; Nasutermitinae (group II) often build their nest in decay wood or in trees. Therefore, the deforestation directly affects the termite habitats and indirectly reduces the organic layers of ground surface leading to the decrease of the species number of Termitinae and Nasutitermitinae.

Distribution of termites by different altitudinal ranges

Altitude is a factor that affects climate characteristics and therefore affects the distribution of flora and fauna. Quang Nam is an area with complex topography, including hills, semi-mountains and coastal plains. In this study, the distribution of termites was analyzed according to the following five altitudial ranges: below 300; 300m – 700m; above 700 – 1,000m; above 1,000 - 1,500m and above 1,500m. The results on the number of species distributed at each altitudial range are summarized in Table 3.

Table 3. Number of species of subfamilies found at different altitudinal ranges in Quang Nam

Science name	<300		300-700		>700-1,000		>1,000 -1,500		>1,500	
	N	P	N	P	N	P	N	P	N	P
Kalotermitinae	1	1.1	3	3.4	1	1.1	2	2.2	1	1.1
Coptotermitinae	2	2.2	1	1.1	2	2.2	0	0.0	0	0.0
Heterotermitinae	0	0.0	0	0.0	5	5.6	6	6.7	3	3.4
Rhinotermitinae	5	5.6	6	6.7	6	6.7	0	0.0	0	0.0
Macrotermitinae	19	21.3	17	19.1	15	16.9	2	2.2	1	1.1
Termitinae	9	10.1	12	13.5	8	9.0	10	11.2	1	1.1
Nasutitermitinae	8	9.0	12	13.5	15	16.9	7	7.9	3	3.4
Total	**44**	**49.4**	**51**	**57.3**	**52**	**58.4**	**27**	**30.3**	**9**	**10.1**

Noted: N: number of species; P: percentage.

The results in Table 3 showed that the highest number of species was obtained at the altitudinal range above 700-1,000m (52 species, accounting for 58.0% of the total species in the study area), followed by the altitudinal range of 301-700m (51 species, accounting for 57.3%), the altitudinal range below 300m (44 species, accounting for 49.4%) the altitudinal range above 1,000-1,500m (27 species, accounting for 30.3%), the last is the altitudinal range over 1,500m (there are 9 species, accounting for 10.1% of the total number of species investigated). Thus, in areas with high terrain (over 1,500m) there will be a poorer termite species composition, lower diversity. Thai Van Trung (1963) commented that, on the general background, Vietnam's climate is tropical, but at different altitudes, specific climate belts are formed. Quang Nam is in the south of Vietnam. If based on the division of Thai Van Trung (1963), the study area can be divided into 3 main climate belts: belts with altitude above 1000m are humid tropical climate belts and belts with altitudes from 1,000-1,500m is a subtropical low mountain climate belt, the belt with altitudes from 1,500-2,400m is a temperate mountain belt. Based on this division, we see that the number of termites tends to decrease from the tropical climate belt to the temperate mountain climate belt.

At the subfamily level, the results show that all 7 subfamilies are found in the altitudinal range from 701-1,000m, the lower and higher altitudinal ranges reduced the number of subfamilies. The subfamilies Kalotermitinae, Macrotermitinae, Termitinae and Nasutitermitinae were found in most of the altitudinal ranges; Heterotermitinae occured only from altitudes above 700m; Coptotermitinae and Rhinotermitinae were not found at altitudials above 1,000m. If we consider the genera and species in each subfamily at the altitudinal ranges, the results showed that the number of species in the genera in the same subfamily at the altitudinal ranges was also different. In the Kalotermitinae subfamily, a small number of species was found in all altitudinal ranges, in which two species of *Cryptotermes* genus were found at altitudes below 300m and conversely five species of *Glyptotermes* genus were found at altitudes above 300m; The number of species belong to Macrotermitinae subfamily always accounts for a large proportion at altitudes below 1,000m, but is much reduced at altitudes above 1,000m. In this study, only *Odontotermes* genus was found at altitudes above 1,000m and *Odontotermes formosanus* is the only species of this genus was recorded at altitudes above 1,500m. The decrease in dominance of subfamily Macrotermitinae has also been seen in many studies such as Nguyen Duc Kham (1976), Nguyen Van Quang (2012). In the subfamily Termitinae, three genera *Microcerotermes, Termes* and *Pseudocapritermes* are found at altitudial ranges below 1,000m; *Discuspidtermes, Mirocapritermes* and *Sinocapritermes* are found at altitudes from 300m up to 1,500m; *Globitermes* and *Pericapritermes* are found in most altitudinal ranges. In the subfamily Nasutitermitinae, most of the genera are found in the high altitudinal range from 301-1,000m, especially the *Ahmaditermes* is typical in high mountains, it is found in high altitudinal ranges above 1,000m. The predominance of genera in each subfamily has also not been mentioned in previous studies.

Conclusion

From our research results, 95 species of termites of 30 genera and 3 families were recorded in Quang Nam. In which, 89 species belonging to 28 genera of the study were obtained and 6 species, 1 genus inherited from previous research documents. The study added 49 new species, 19 new genera to the study area and 10 new species and 1 new species for the termite fauna of Vietnam. In six studied habitats, the number of species was the largest in the secondary forest habitat has (70 species, accounting for 78.7% of the total species collected in the study area), followed by primary forest (42 species, accounting for 47.2%), plantation forest (30 species, accounting for 33.7%), mountain field (17 species, accounting for 19.1%), dams (15 species, accounting for 16.9%), the least number of species was in residential area (13 species, accounting for 14.6%). The study analyzing the distribution by altitude ranges has recorded that the highest number of species was found at the altitudinal range above 700-1,000m (52 species, accounting for 58.0% of the total species in the study area), followed by above 300-700m (51 species, accounting for 57.3%), below 300m (44 species, accounting for 49.4%), above 1,000-1,500m (27 species, accounting for 30.3%) and above 1,500m (9 species, accounting for 10.1% of the total number of species).

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Thursday | March 2, 2023 | 15:30-15:45

O_03

The desiccation tolerance of termite community in urban area

by

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Abstract

Urbanization was hypothesized selecting termites with high desiccation tolerance and change termite community. To test this hypothesis, we installed a total of 100 underground traps in urban and forest areas in Khon Kaen Province, and monitored the traps biweekly for one year to understand the termite diversity. Termites were collected for quantifying their water loss rate and mortality under 0% RH. A total of 14 termite species were detected in underground traps, and the diversity of termite in forest area (14 species) was higher than that in urban area (10 species). Analysis on water loss rate showed that desiccation tolerance is different among termite species. Highest water loss rate were observed in subterranean litter-feeding termites, *Microterme*s, *Odontotermes* and *Ancistrotermes*, followed by subterranean wood-feeding termite, *Globitermes*, arboreal wood-feeding termites, *Nasutitermes* and *Microcerotermes*, and ground litter-feeding termites *Macrotermes*. The most desiccation-tolerant genera, *Nasutitermes*, and *Microcerotermes*, were not observed in urban area, which does not support the hypothesis that desiccation-tolerant species are selected in urban area. We suggest that desiccation tolerance is majorly associated with foraging habitat.

Key words: water loss rate, mortality rate, urbanization

Introduction

The expansion of urban area is an ongoing process over the world (Seto et al., 2012), and the urbanization may lead to changes on biotic and abiotic environment, and may change biological communities (McDonnell and Pickett, 1990; Feng et al., 2021). For example, urbanization may increase the environmental temperature and CO_2 levels, and further reduce the environmental humidity, as well as the water and nutrient contents in soil (Johnson and Munshi-South, 2017). Urbanization may negatively affect the diversity and abundance of beneficial insect community, such as pollinators (Wenzel et al., 2020), and positively affect the diversity and abundance of insect pests (Frankie and Ehler, 1978; Colunga-Garcia et al., 2010). Insect pests were considered adapt and survive in urban habitats through their preadaptation characters (Frankie and Ehler 1978; McKinney, 2002), such as heat and desiccation tolerance (McKinney, 2002).

Desiccation tolerance is largely different among termite species, and could affect termites' survival in harsh environment (Collins, 1969; Shelton and Grace, 2003; Hu et al., 2012; Woon et al., 2018). High desiccation tolerance was observed in family Kalotermitidae, such as *Cryptotermes* spp., which was suggested as an adaptation to arid environments (Collins and Richards, 1966; Collins, 1969).

In Thailand, there are a variety of Termitidae species living in urban areas, and their desiccation tolerance may contribute to their survival in urban areas. The aim of this study is to examine (1) the differences of termite community in urban and forest areas; (2) whether the desiccation tolerance of termites in urban area are higher than that in forest area.

Materials and methods

Study site and termite sampling

To investigate termite community, we installed a total of 100 termite traps at 10 localities in Khon Kaen University, Thailand, including 5 localities in forest and 5 localities urban areas (Fig. 1A). The distances among study localities are >100 m. In each locality, 10 termite trap stations were installed in a line with a 5-m interval. Termite traps were plastic box (21.1 × 16.5 × 10.8) containing a paper roll (diameter: 13 cm, height: 9.8 cm). The bottom of traps were cut off to allow termites to access the paper roll (Fig. 1B). All stations were buried underground with a depth of 10 cm. After installation, traps were inspected every 2 weeks to record termite occurrence, from August 2021 to August 2022. The paper rolls consumed for >50% were replaced with new ones. For each termite species observed in trap, three colonies from different localities were brought to laboratory for species identification and analysis of desiccation tolerance. Thirty individuals of termite soldiers and workers were collected from each colony and preserved with 95% alcohol, and were identified based on soldier morphology, according to the systematic key of termites of Thailand (Sornnuwat at al., 2004; Ahmad, 1965).

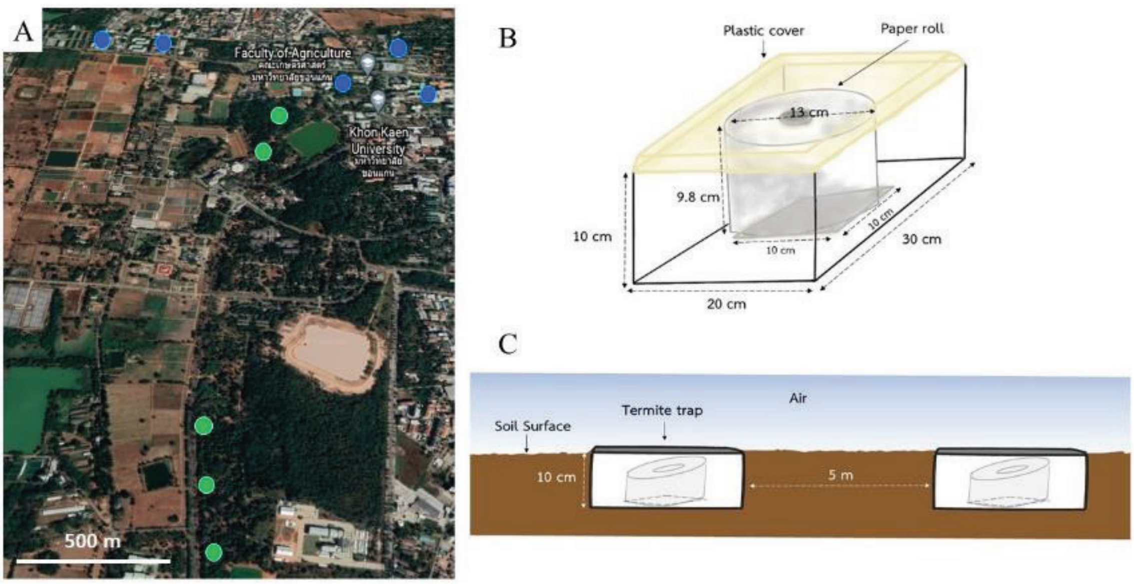

Fig. 1 Locations for setting up termite traps, including 5 locations in forest and 5 locations in urban areas (A). Structure of termite trap (B). Method to install traps, traps were installed with a depth of 10 cm and a 5 meter interval (C).

Analysis of water loss and cuticular permeability

Gravimetric method was used to analyze the water loss rate of termites. In each trial, 10 individuals were placed in a 5-mL plastic tube, and the tube was placed in a desiccation box (Volume: 1L, Model: HPL817, LocknLock) which was filled with 1 kg molecular sieves 5A to keep a 0% relative humidity inside the container. The weight loss and mortality of termites are recorded at 6, 12, 24, 48, 96, 192, 384, 768, and 1,532 minutes after placing into the box (Appel, 1993; Shelton and Grace, 2003). Afterward, the tube was placed in an oven, kept at 55 °C for 72 hours, for measuring the dry weight of termites. This trial was replicated for three times for major worker caste of each colony of each species. The water loss rate at time t (WL_t) was calculated using the following formula:

$$WL_t(\%) = \frac{W_t - W_f}{W_f - W_d} \times 100$$

where W_t is the weight of termite at time t, W_f and W_d are fresh weight and dry weight of termites.

Statistical analysis

For each termite species, the water loss (WL_t) at time *t* was fitted as dependent variable in a polynomial regression model to estimate water loss rate:

$$Y_t = R_1 t + R_2 t^2 + B$$

where R_1 and R_2 are linear and non-linear water loss rate (percentage/min.), respectively, and B is the intercept of model. Differences on linear water loss rate (R_1) among species were compared using ANOVA with Tukey's HSD test. All statistical analyses were conducted using R programming language (v.3.3.1).

Results and Discussion

Termite community in urban and forest area

A total of 14 species of seven genera were observed in traps, including arboreal wood-feeding termites, *Nasutitermes* and *Microcerotermes*, subterranean litter-feeding termites, *Microterme*s, *Odontotermes* and *Ancistrotermes,* ground litter-feeding termites *Macrotermes*, as well as subterranean wood-feeding termite, *Globitermes*. All termites belong to the family Termitidae, which is the most abundant family in tropical areas and accounts for ~75% of termite diversity over the world (Chellappan and Ranjith, 2021). Arboreal wood-feeding termites were not observed in urban area, and higher occurrence of subterranean litter-feeding termites were observed in forest area (Fig. 2.), support that termite diversity and abundance were higher in forest area. Considering that forest is the major source of litters (Lavelle, 1996), we propose that the high abundance of subterranean litter-feeding termites is associated with litter abundance in forest area. Similar results were also observed by Davies (1997), Materu et al. (2013), and Lee (2002), which reported that high diversity and abundance of litter-feeding termites in forest area.

Previous studies indicated that *Microcerotermes* is the prevalent in rural areas of Malaysia (Kirton, 1995), and we found that genera *Microcerotermes* did not occur in our underground traps in urban area. We propose that *Microcerotermes* is less abundant in urban area due to its open-air foraging behavior, which is more likely observed and cleared by human. Okwakol (2000) reported that the abundance of *Microtermes* was not affected by human disturbance. In this study, we found that *Microtermes* and *Globitermes* has similar occurrence rate in forest and urban areas, which also supports the idea that disturbance less affect the abundance of *Microtermes*.

Coptotermes spp. are important pests in urban areas, farmlands (Su and Scheffrahn, 1990), and forests (Chiu et al., 2016) over the world, and they were reported attacking trees and caused center-hollowing in large trees (Greaves, 1962). In Thailand, *Coptotermes gestroi* is the dominant structure pest in cities and could be trapped using papers and underground traps. For example, Sornnuwat et al. (1996) used underground traps with corrugated paper rolls and rubber wood stakes (*Hevea brasiliensis* Muell) to collect *Coptotermes gestroi*. Similarly, Chiu et al. (2016) modified the original underground trap from Su et al. (1993) to monitor *Coptotermes gestroi*. However, we found no *Coptotermes* spp. in traps in this study. We propose that the foraging activity of *Coptotermes* was low in soil due to their competitions with litter-feeding termite population, which is hypothesized by Chiu et al. (2016).

Water loss rate and mortality

Desiccation tolerance of animals is generally improved by physiological or physical mechanisms that reduce water losses (Hadley, 1994). For termites, the major water loss route is through cuticular walls, accounting for 89.1-93.5% of total water loss (Woon et al., 2018; Shelton and Appel, 2000). Different humidity permeability of cuticle may result different humidity equilibriums in termites (Zukowski and Su 2019), and allow them to adapt different environments. For example, the low cuticle permeability was observed in termite species inhabit arid environments (Collins and Richards, 1963). *M. carbonarius*, which frequently perform open-air foraging behaviors (Inoue et al., 2001), was found having a lower surface area to volume ratio, absolute and relative water loss rate, compared to congeneric species (Hu et al., 2012), *M. gilvus*, which forages below ground (Acda, 2004).

In this study, we found that the water loss was significantly different among genera (Fig. 2). Highest linear water loss rate was observed in small-sized subterranean litter-feeding termites, including *Microtermes* (R_1 = 0.6502±0.1484, R^2 = 0.9779), *Odontotermes* (R_1 = 0.5029 ± 0.0912, R^2 = 0.9812), and *Ancistrotermes* (R_1 = 0.4391 ± 0.0153, R^2 = 0.984), followed by small-sized subterranean wood-feeding termites, *Globitermes* (R_1 = 0.1695 ± 0.0118, R^2 = 0.9846), arboreal wood-feeding termites, *Nasutitermes* (R_1 = 0.1249 ± 0.0049, R^2 = 0.9962) and *Microcerotermes* (R_1 = 0.0718 ± 0.0164, R^2 = 0.9804), and ground litter-feeding termites, *Macrotermes* (R_1 = 0.0711± 0.0170, R^2 = 0.9993) (Fig. 2). The absence of arboreal wood-feeding termites in urban areas, did not support the hypothesis that desiccation tolerant species are selected in urban area. Instead, desiccation tolerance is more likely selected by foraging habitat of termites.

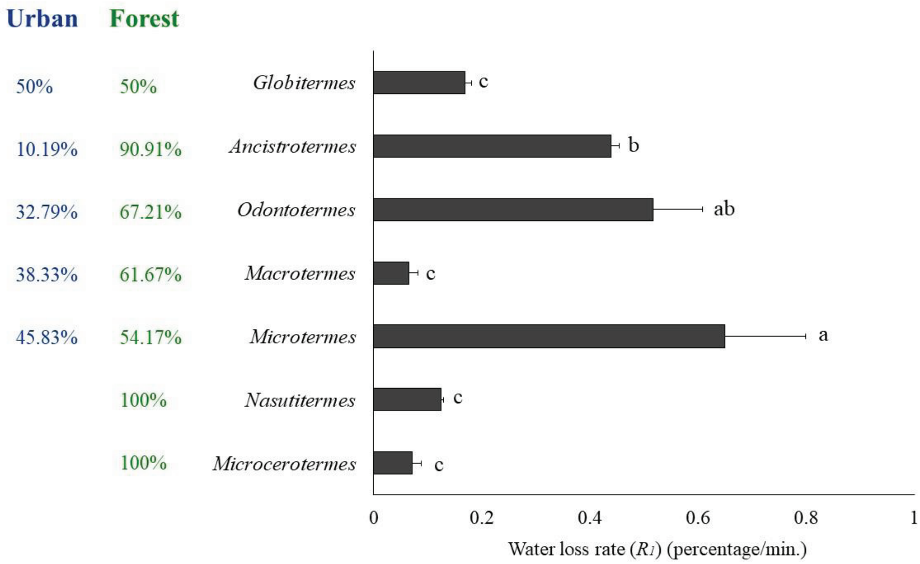

Fig. 2 The differences on linear water loss rate (R_1, mean ± SD, %/min.) among termites. Bars with the same lowercase letter are not significantly different (P>0.05, ANOVA with Tukey'HSD).

Conclusion

In conclusion, this study showed a total of 14 termite species, our results indicate that the diversity of termite in forest area was higher than that in urban area. Analysis on water loss rates showed that desiccation tolerance is not associated with urban or forest areas, but more likely associated with termites foraging habitats.

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O_04

Non-mendelian families of Formosan subterranean termite found in Taiwan

by

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Abstract

Formosan subterranean termite, *Coptotermes formosanus* Shiraki, is one of the world's worst invasive pests. Their breeding structure in the field is still a mystery because of the nests and royal cells of *C. formosanus* were difficult to find. The colony structure of termite can be divided into three types, simple family, extended family and mixed family. Previous studies had found both mendelian colonies (simple family) and non-mendelian colonies (extended family or mixed family) of *C. formosanus* in the field. The researchers speculated that all of the non-mendelian colonies they found were extended families (colony with functional neotenic) but not mixed family (fused colony or colony with pleometrosis). Considering there was no study proving the function of neotenic in *C. formosanus*, and a recent study showed *C. formosanus* may have the ability to form mixed family in the field. We argued that whether the non-mendelian colonies were extended family or actually mixed family needs to be re-examined. In this study we reported the non-mendelian families also appeared in Taiwan, which is one of the native areas of *C. formosanus*. Simple family of *C. formosanus* do exist in Taiwan, however, the other two breeding structures, extended family and mixed family, could not be excluded as well.

Key words: supplementary reproductive, colony structure, colony fusion, microsatellite

Introduction

Coptotermes formosanus was originated from Southern China and Taiwan (Liang et al. 2020). By gradually colonizing the urban habitats around the world, they were estimated to cause tens of billions of US dollars annually on construction repair and pest control (Rust and Su 2012), and becoming the world's worst invasive termite pests. Even as such an important pest, the breeding system and the colony structure of *C. formosanus* has not been carefully understood.

The colony structure of termite can be divided into three types based on the source and number of the reproductives: 1) Simple family, the colony consisting of the primary monogamous pair and their offspring. The genotypes of the foragers followed the Mendel's law of inheritance 2) Extended family, the primary monogamous pair in the colony was supplemented or replaced by supplementary reproductives which were descended from the monogamous pair. 3) Mixed family, the colony members were produced by multiple unrelated reproductive. It can be achieved by pleometrosis or adopting new colony members from different colony (colony fusion).

A colony of *C. formosanus* was found by a monogamous pair of alates. Although pleometrosis were observed under laboratory condition, they cannot survive longer than 6 months (Osbrink et al. 2016). Nests and royal cells of *C. formosanus* were difficult to find, and it is not practical to observed the colony structure directly. Therefore, many studies determine the breeding structure of *C. formosanus* by genotyping foragers and infer the number of reproductive (Vargo et al. 2006, Vargo et al. 2003, Husseneder et al. 2012). These studies do find that in US, Japan, and China, *C. formosanus* colonies could have a genetic structure different from that of the simple family in the field. Although the existence of the neotenic of *C. formosanus* have been observed (Raina et al. 2004, Chouvenc et al. 2022), the reproductive ability of these neotenics are still unknown, and no detailed examination on the function of these neotenic has been made so far.

Previous studies tested the family structure on the *C. formosanus* populations assumed that those non-mendelian colonies were all extended families (Vargo et al. 2006, Vargo et al. 2003, Husseneder et al. 2012). Now we know *C. formosanus* may have the ability to form mixed family in the field. One colony fusion event was observed in the field (Su and Scheffrahn 1988, Chouvenc et al. 2022) and the possible scenarios has been tested in the laboratory condition (Lee et al. 2019). The possibility of mixed family should be considered when judging the breeding structure of *C. formosanus*.

Previous research supports that non-mendelian families of *C. formosanus* may be a widespread phenomenon whether in native population and introduced populations (Husseneder et al. 2012). However, the data in Taiwan, which is one of the native populations of *C. formosanus*, was still lacking. In this study, we examined the genetic diversity of the five markers in the Taiwanese population in order to screen for makers with sufficient resolution (higher diversity), and we examined that whether non-mendelian families appeared in the field of Taiwan.

Materials and Methods

Five monitoring plots (Plot A-E) were set within the campus National Chung Hsing University (NCHU). Monitoring inrground stations (Sentricon stations with wood monitors, Dow AgroSciences) were installed on the ground in four plots (plot A-D) with their area vary from 100m^2 to 600m^2, and in plot E stations were installed on a huge Shen-mu ("holy giant tree" in Chinese, a kind of decoration made with big fallen tree in Taiwanese culture) invested by termites. The stations were checked on a monthly basis. The Recruit® HD termite baits were installed in one station where termite activities were found for each plot in Plot A, Plot C, Plot D, and Plot E. Three baits were installed in Plot B where termite activities were found. The monitoring in Plot A-C started from 2022 February to August; The monitoring in Plot D started from 2022 August to December; The monitoring in Plot E started from 2021 June to September. At least 30 workers were collected per station whenever available.

The termite samples collected in the study were preserved in 95% alcohol. If the individual number was more than 30, then 30 individuals were selected for microsatellite genotyping. If the number was smaller than 30, a few individuals were left as voucher specimens and the rest were taken for the genotyping. DNA extraction method was modified from Meeker et al. (2007). A set of microsatellite genetic markers *CopF6F*, *CopF10F*, *Cg33*, *CopF10-4*, and *Clac1* were employed for subsequent analysis (Chouvenc et al. 2017). A 10 µL PCR reaction contained 1 µL of template DNA, 1X amaR OnePCR^{TM} master mix (final concentration). In the reaction, for the loci *CopF6F*, *CpoF10F*, and *CopF10-4*, 100 nM of forward primer, 200 nM of reverse primer, and 40 nM of M13 (-19, 5'-CAC GAC GTT GTA AAA CGA C-3') fluorescent primer were added; for loci *Clac1* and *Cg33*, 350 nM of forward primer, 200 nM of reverse primer, and 24 nM of M13 fluorescent primer were added. Loci were amplified on a SensoQuest Labcycler thermal cycler (SensoQuest Biomedizinische Elektronik GmbH, Gottingen, Germany). The cycling program is as follows: initial denaturation step at 95 °C (5 mins), followed by 27 cycles of 95 °C (30 s), 55 °C (30 s) and 72 °C (30 s), and then 8 cycles of 95 °C (30 s), 50 °C (30 s) and 72 °C (30 s), with a final extension step at 72 °C (5 min). Loci amplified by PCR were sent to Genomics Center for Clinical and Biotechnological Applications of National Core Facility for Biopharmaceuticals, Taiwan (NSTC 111-2740-B-A49-001) for sequencing. Allele calling was performed in the software Geneious (version 2020.2).

Under the assumption of a single king and a single queen, there are a total of 7 possible combinations, these 7 forms are presented in the form of Punnett square. After obtaining the microsatellite sequences of each individual, we recorded the genotypes that appeared in the bait station, and deduce the parental genotype according to the Punnett square. If multiple bait stations have the same parental genotype, it means that the termites that invaded these bait stations come from the same colony. If we cannot reconstruct the parental genotype, it means the colony was not a Mendelian population (simple family). The colony could be extended family or mixed family. If we find a colony with more than five alleles on one locus, we can conclude that it is a mixed family. In other words, if the genetic diversity within the population is low (allele number <5), it is impossible to distinguish extended family and mixed family.

Results and discussion

A total of 2105 individuals from the five plots in NCHU were genotyped. In Plot A, Plot C, Plot D, and Plot E, termite population were eliminated in two months by using only one Recruit® HD termite bait, which indicates that the population was produced by the same colony in each plot.

In plot A, 3 stations (numbered A1-A3) were invested by termite among the 16 monitoring stations, and a total of 90 individuals were used for microsatellite genotyping. The loci were successfully amplified (98.2%), and their genotype were used to reconstruct their parental genotype (Table 1). Since all stations follow with Mendel's law of inheritance and having the same parental genotype, indicating that they all come from the same colony, and the breeding structure of the colony was simple family.

Table 1. Genotypes of *C. formosanus* foraging individuals from plot A, as an example of simple family

locus/genotype		A-1	A-2	A-3	Parent 1	Parent 2
CopF6F	191/202	2	9	7	191/204	202/206
	191/206	12	9	6		
	202/204	11	2	10		
	204/206	4	10	7		
CopF10F	350/350	29	30	30	350/350	350/350
CopF10-4	152/152	7	9	9	152/164	152/170
	152/164	7	3	6		
	152/170	8	12	9		
	164/170	7	6	6		
Clac1	197/199	9	5	6	197/208	199/206
	197/206	4	9	12		
	199/208	9	7	3		
	206/208	5	9	9		
Cg33	214/214	28	28	28	214/214	214/214

In plot B, 13 stations (numbered B1-B13) were invested by termite among the 30 monitoring stations, and a total of 444 individuals were used for microsatellite genotyping. The loci were successfully amplified (97%), and their genotype were used to reconstruct their parental genotype (data not showed). Since all stations follow with Mendel's law of inheritance and having the same parental genotype, indicating that they all come from the same simple colony.

In plot C, 6 stations (numbered C1-C6) were invested by termite among the 14 monitoring stations. and a total of 187 individuals were used for microsatellite genotyping. The loci were successfully amplified (95.7%), and their genotype were used to reconstruct their parental genotype (Table 2). On the locus CopF10-4, most of the individuals in the six stations have the genotype 173/180 (n=84) or 173/189 (n=83). The data fitted the expected ratio 1:1 if the parental genotype were 173/173 and 180/189, however, one individual carrying 173/173 and the other one carrying 173/185 was found (Table 2). We got the same result by doing the PCR and the allele calling once again. The genotypes we found on this locus was apparently not produced by a simple family, since no monogamous pair can produce a brood with the genotypes 173/173, 173/180, 173/185 and 173/189. Because the number of alleles were not more than 4, we cannot tell whether the colony is extended family or mixed family categorically. It could be an extended family with a pair of reproductives (173/173 and 180/189) were at work, as most of the offspring were 173/180 or 173/189 (98.8%). The genotype 173/173 and 173/185 may be produced from older generations. On the other hand, the colony could be a mixed family produced by colony fusion. Where there were two colony fused, one carrying the genotypes 173/180, and 173/189, and the other carrying 173/173 and 173/185.

In plot D, 9 stations (numbered D1-D9) were invested by termite among the 21 monitoring stations, and a total of 252 individuals were used for microsatellite genotyping. The loci were successfully amplified (97.9%), and their genotype were used to reconstruct their parental genotype (data not showed). Similar to the scenario of Plot C, on the locus CopF10-4, one individual was found carrying a unique genotype different from the others, which made the genotype combinations to go against the Mendel's law of inheritance. Because the number of alleles were not more than 4, we cannot tell whether the colony is extended family or mixed family.

Table 2. Genotypes of *C. formosanus* foraging individuals from plot C, as an example of non-mendelian family.

locus/genotype		C-1	C-2	C-3	C-4	C-5	C-6	Parent 1	Parent 2
CopF6F	193/202	8	7	5	7	7	8	202/193	202/206
	193/206	4	11	6	11	5	4		
	202/202	6	5	10	8	10	6		
	202/206	11	7	6	3	8	12		
CopF10F	346/346	1	7	6	5	10	5	346/350	346/350
	346/350	19	14	18	15	12	14		
	350/350	9	9	6	9	8	11		
CopF10-4	173/173			1*				Multiple reproductives	
	173/180	14	14	14	13	17	12		
	173/185			1*					
	173/189	15	16	14	7	13	18		
Clac1	206/206	18	17	12	12	17	13	206/206	206/208
	206/208	11	13	13	15	12	17		
Cg33	214/214	27	27	27	27	27	27	214/214	214/214

In plot E, a total of 16 stations (numbered E1-E16) where termite activities were found, and a total of 132 individuals were used for microsatellite genotyping. The loci were successfully amplified (96.2%), only six stations, E-2, E-3, E-4, E-5, E-6, and E-10, had more than 10 individuals collected and sequenced. Since all stations follow with Mendel's law of inheritance and having the same parental genotype, indicating that they all come from the same simple colony (data not showed).

In the study we found that non-mendelian colony did exist in Taiwanese population (2 colonies within 5), again suggest this phenomenon were widespread in whether it is native population or introduced populations (Vargo et al. 2006, Vargo et al. 2003, Husseneder et al. 2012). The allele number detected in these non-mendelian colonies were not larger than 4, it is still inconclusive on the two possible breeding structures. In the future we will obtain the mtDNA sequences of the individuals in these non-mendelian colonies, if colony fusion did happen, the individuals should carry different mtDNA haplotype.

Loci were successfully amplified, and 6, 2, 11, 5, and 1 allele were detected on the locus *CopF6F*, *CopF10F*, *CopF10-4*, *Clac1*, and *Cg33* within the 36.3 ha area of the campus NCHU. *CopF10-4* showed the highest diversity (11 alleles), and the two non-mendelian colonies were detected because of the non-mendelian genotype combinations were found on the marker *CopF10-4* while the data on the other four markers still follow the Mendel's Law. This confirms the importance of genetic diversity in detecting colony structure. Study had shown that marker diversity could be more important than the number of markers being used (Sefc and Koblmüller 2009), and there is no doubt that using high diversity markers can reduce the cost of experiments. Further study will employ more markers with higher diversity to get higher resolution.

Conclusion

Coptotermes formosanus foragers in five monitoring plots in the campus NCHU were genotyped, the microsatellite data and the results of bait treatment indicate they were five individual colonies, one for each plot. The results show two of the five colonies were non-mendelian family. Since we cannot exclude the possibility of the colonies being as extended family or mixed family, more information should add the assessment like whether the colony members carrying different mtDNA haplotype. To get higher resolution more markers with higher diversity were needed.

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Thursday | March 2, 2023 | 16:00-16:15

O_05

Anatomical structure of pronotum setae in the soldier of subterranean termites *Coptotermes* spp. (Blattodea: Rhinotermitidae)

by

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Abstract

The soldier caste morphology of termites is specifically developed to perform defensive tasks inside and outside the nest. Defensive-related morphologies include a massive head capsule, a transformed fontanelle, and well-developed mandibles. Apart from the commonly known body parts, the body setae of soldier termites were suggested to develop more than those of workers. Setae characteristics are also specific and generally used in the discrimination of subterranean termite species. However, the functional importance has remained unclear, particularly on the pronotum part. Thus, we illuminated the putative function of pronotum setae based on ultrastructural analysis. The ultrastructure demonstrated that the setae were innervated, some have a single pore on the tip with two types of cells' outer segments. This type of seta is presumed to be contact-chemotype sensillum, and in general, the mechanoreceptor is supported by the long-peg morphology with a flexible socket around the seta. The single pore on the tip of the seta exists together with the elongation of chemoreceptor cells' outer segments in the setae lumen. Differences in the distribution of setae in the pronotum among *Coptotermes* spp. may be due to differences in the peripheral sensory system between the species, which may affect their habitat preferences.

Key words: setae, morphology, electron microscopy, sensilla, sensory system

Introduction

The morphological modifications take place due to the different ways of life of the insects during evolution. The pressure of food source competition, habitat preference, and predators may affect the differentiation of insects' body part morphology, such as antennae, tarsal part, mandibles or jaws, head capsule, etc. (Patterson 1984, Bernays et al. 1991, Scheffrahn et al. 1998). The morphological modifications are more obvious in social insects that have physical caste. The Jataí bee guard caste *Tetragonisca angustula*, has a bigger body, longer legs, and smaller head size compared to the forager, as they prefer to grapple the intruder with the legs instead of performing powerful biting (Grüter et al. 2012). The big-headed ant guard *Pheidole megacephala* had a bigger head capsule when they have more competitive ants around them (Wills et al. 2014).

In termite soldiers, the structural modifications affect not only the defensive-morphological characteristics such as head capsule, muscles, and mandibles (Scheffrahn et al. 1998, Koshikawa et al. 2002, Matsuura 2002, Seid et al. 2008, Kaji et al. 2016, Kuan et al. 2020), but also their body setae as their peripheral sensory system (Ishikawa et al. 2007). The importance of the antennae of *Coptotermes formosanus* was suggested as olfactory organs based on the sensilla observation (Tarumingkeng et al. 1976, Yanagawa et al. 2009, Yanagawa et al. 2010, Fu et al. 2020). However, setae on other body parts are less studied. In fact, setae are distributed on the whole body of the soldier termite, not just on the antennae, which allows for the discrimination of several subterranean termite species (Takematsu 1999, Constantino 2000, Bourguignon and Roisin 2011). The anatomy of the setae on soldier termite's body is also unknown.

In this study, the anatomical structure of the pronotum setae in subterranean termites *Coptotermes* spp. was described. The ultrastructure analyses were conducted by utilizing electron microscopy analysis.

We inferred the presumed function of each type of setae by observing the structure of the cuticle and its outer sensory cells' segments.

Materials and Methods

Termite specimens

Three species of Indonesian *Coptotermes* were used in the morphology analysis (63 individuals for each species), namely *Coptotermes curvignathus* (Bogor, Indonesia), *C. gestroi* (Bogor, Indonesia), and *C. sepangensis* (Batam, Indonesia). One Japanese *C. formosanus* (Lab. Colony, Kyoto University, Japan) together with *C. curvignathus* and *C. gestroi* were used in the ultrastructure analysis (18 specimens in total).

Anatomical analysis

The morphology characteristic of the pronotum and its setae numbers were collected. The medial length and width of the pronotum were measured. The setae numbers characteristic was divided into three groups based on their location on the pronotum (total, medial, and marginal setae). The data variance was descriptively explored by statistical packages IBM SPSS Statistics 27 (IBM Corp, Armonk, New York, NY, USA).

The outer cuticle structure of the setae was analyzed by scanning electron microscopy with JSM-7800F scanning electron microscope (JEOL) at a 5kv accelerating voltage. An aqueous osmium tetroxide (OsO_4) solution was used for staining. Platinum coating (20 mA for 120 s) was done with an auto-fine coater (JEC-3000FC; JEOL, Tokyo, Japan).

The ultrastructure analysis of the setae was performed by transmission electron microscopy with JEM-1400 (JEOL) at 120 kV accelerating voltage. A mixture of glutaraldehyde (2%) and paraformaldehyde (2%) in phosphate-buffered saline (PBS) was used for specimen fixation. A mixed solution of PO and Spurr resin (Polysciences, Warrington, PA, USA) was used for impregnation. A 70 nm thickness of specimen sectionings was obtained with a diamond blade (ultra 45°; Diatome, Nidau, Switzerland) in an ultramicrotome (Ultracut E; Reichert-Jung, Wetzlar, Germany). Final staining was conducted with uranyl acetate (2.5%) in ethanol (50%) and Reynold's lead citrate solution.

Results and discussion

Setae distribution characteristics on imago and soldier, particularly on pronotum, are important for species diagnosis in Rhinotermitidae (Bourguignon and Roisin 2011, Takematsu and Vongkulang 2012, Lee et al. 2015). The distribution of setae on the pronotum was generally found to differ among *Coptotermes* spp. (Wikantyoso et al. 2021). In total, *C. curvignathus* had the highest setae numbers compared to *C. gestroi* and *C. sepangensis*. Based on the position of setae on the pronotum, the numbers of setae on the marginal part of *C. gestroi* and *C. sepangensis* overlapped. However, on the pronotum medial part, *C. gestroi* had the least setae numbers compared to the other two species (Fig. 1 and 2A–C). The setae number on the pronotum medial part of *C. gestroi* was more consistent compared to other species, with less variance in the data (σ^2, CC: 59.57; CG: 1.73; CS: 12.83). Hence, pronotum setae medial distribution was considered reliable as *C. gestroi* species' diagnostic character (Violle et al. 2007, Mlambo 2014).

The modified characteristic of fewer pronotum setae thus may have their importance that affects soldier termites' performance as the characteristic was conserved across the samples of *C. gestroi*. Further analysis of the outer morphology of the setae cuticle showed that there were three types of setae, and all types were innervated; a short-tapered peg, a tight flexible socket, and one dendritic-outer segment as a tubular body at the base of the peg (S1) (Fig. 2D, G) and longest pegs which was mostly located on the medial part (S2) and those on the marginal part (S3) of the pronotum. Both S2 and S3 types showed longer sensilla pegs, wider flexible sockets, and three to four dendritic-outer segments. One segment terminated as a tubular body at the base of the peg and the rest segments were elongated to the tip of the peg (Fig. 2E–H).

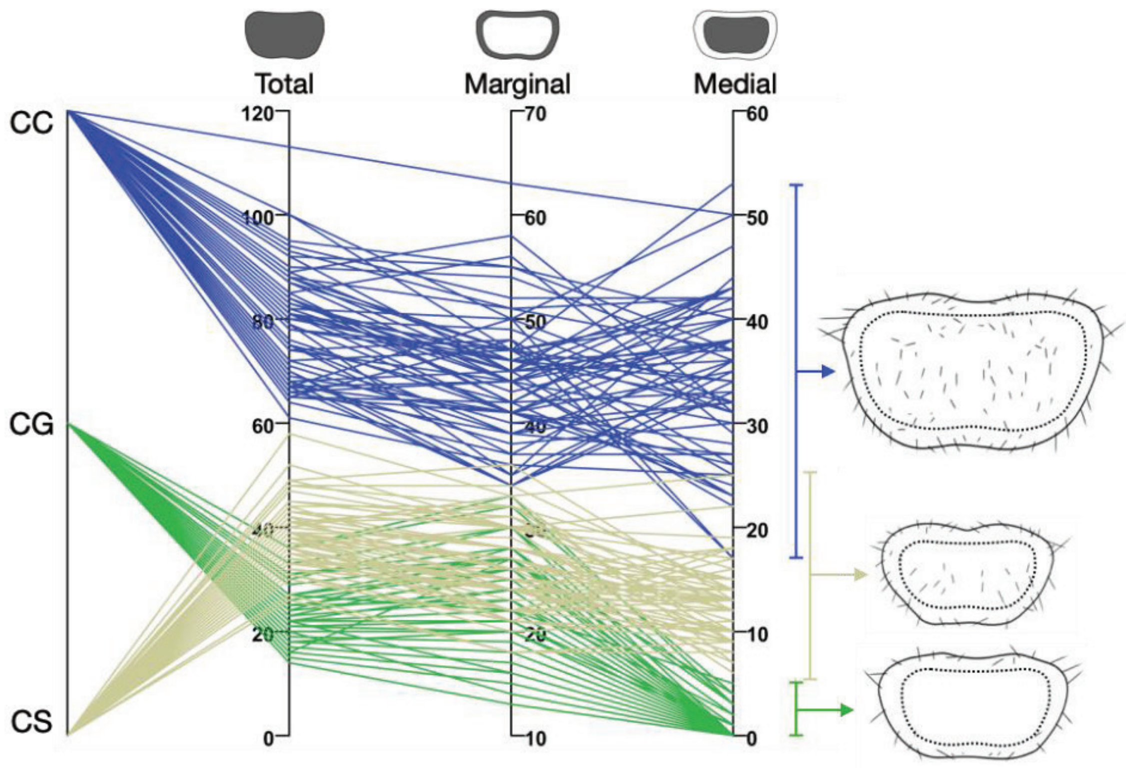

Fig. 1 The distribution of setae in the whole part, marginal part, and medial part of the pronotum. CC: *C. curvignathus*; CG: *C. gestroi*; CS: *C. sepangensis*. Parts of the data and figure were modified from Wikantyoso *et al* (2021).

The electron microscopy analysis of the pronotum setae demonstrated that the body setae characteristic possessed anatomical structure to be beneficial as sensory receptors. The S1 type seta has characteristics of a mechanoreceptor by having the tubular body to sense peg and cuticle distortion (Thurm 1965, McIver 1975, Iwasaki et al. 1999, Wikantyoso et al. 2022). The availability of flexible sockets and the addition of three to four elongated dendritic-outer segments in the peg lumen of S2 and S3 type showed the anatomical structures of mechano-chemoreceptor or tactile sensor (Hansen and Heumann 1971, Tarumingkeng et al. 1976, Wikantyoso et al. 2022). The flexible socket might give flexible movement to the sensilla peg which causes cuticle distortion sensed by the tubular body (Fig. 3). Thus, the characteristics of S1–3 on the pronotum pointed to the anatomical structure beneficial for sensing various substrate-chemical and mechanical signals, such as faint touch or airborne vibration that deflects the peg (Hansen and Heumann 1971, Dumpert and Gnatzy 1977, Tautz 1977, Shimozawa and Kanou 1984, Keil 1997). These structures might influence the behavior of the soldier termites (Statzner et al. 2004, Bonada et al. 2007). Future studies, including electrophysiological analysis, are needed to elucidate the function of each seta.

Conclusion

In *Coptotermes* spp., the setae distribution on the pronotum was diversified. The medial setae distribution of the pronotum in *C. gestroi* is a consistent and reliable feature for diagnosing the species. Body setae on *Coptotermes* spp. are considered as biological characteristics that had an anatomical structure as sensilla or sensory receptors. Ultrastructural analysis revealed the presence of multiple cells at the setae base with flexible sockets and long pegs that appeared to be mechanoreceptor or chemoreceptor cells, as well as the extension of the outer segments in the setae lumen.

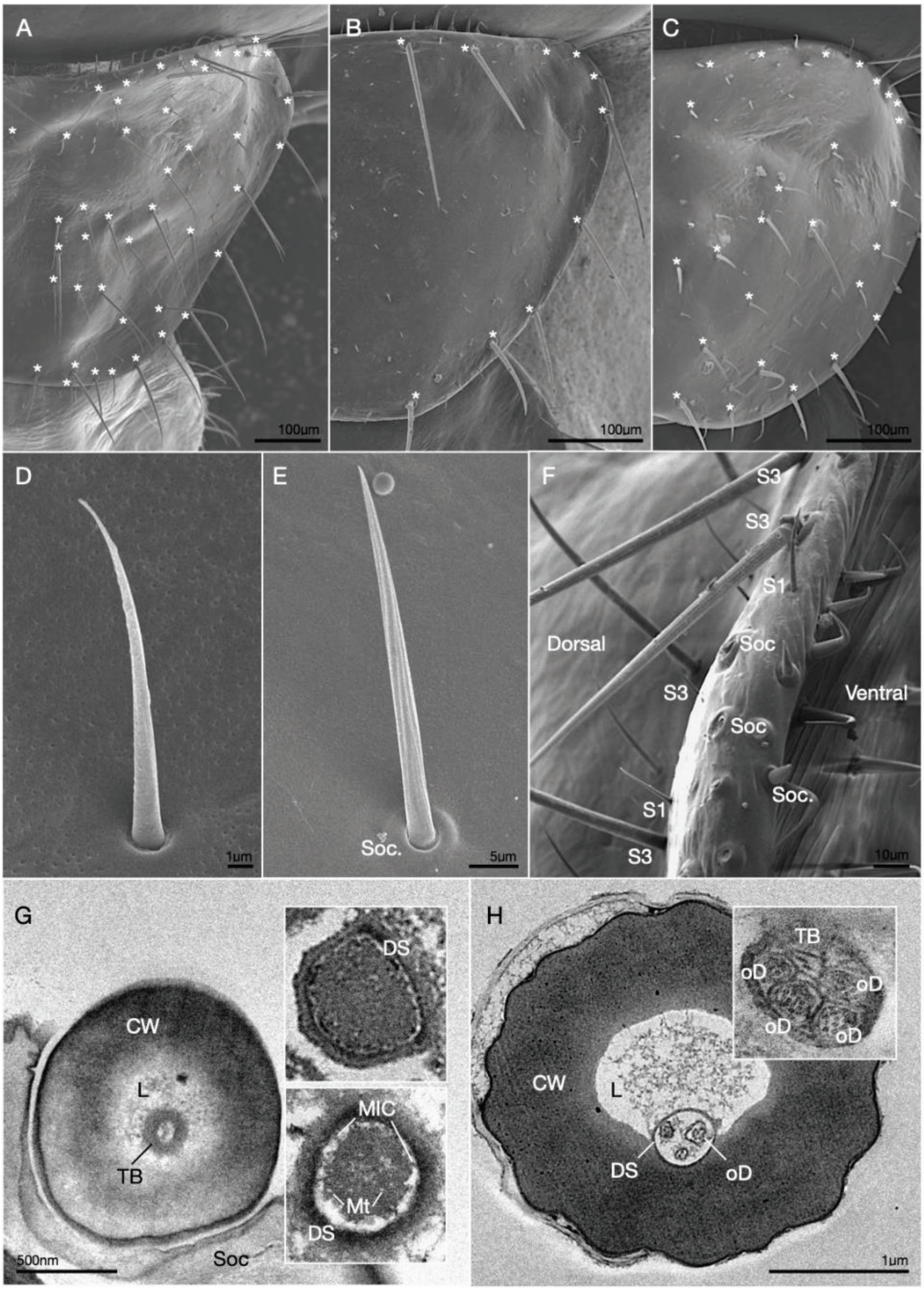

Fig. 2 The ultrastructure of flexible setae on *Coptotermes* spp. pronotum. A–C: The distribution of flexible setae on the pronotum of *C. curvignathus*, *C. gestroi*, and *C. formosanus*, respectively; D–F: The closer view of S1 with tight socket, S2 with wider flexible socket, and S3 location on the marginal side of the pronotum, respectively. G–H: the elongation of dendritic-outer segments on the S1 as mechanoreceptive sensilla by having a tubular body and S2/S3 as mechanoreceptive sensilla by having a tubular body and four chemosensory cell outer segments. Asterisks: flexible setae, CW: cuticle wall, DS: dendritic sheath, L: lumen, MIC: membrane-integrated cones, Mt: microtubule, oD: dendritic-outer segment, Soc: flexible socket, TB: tubular body.

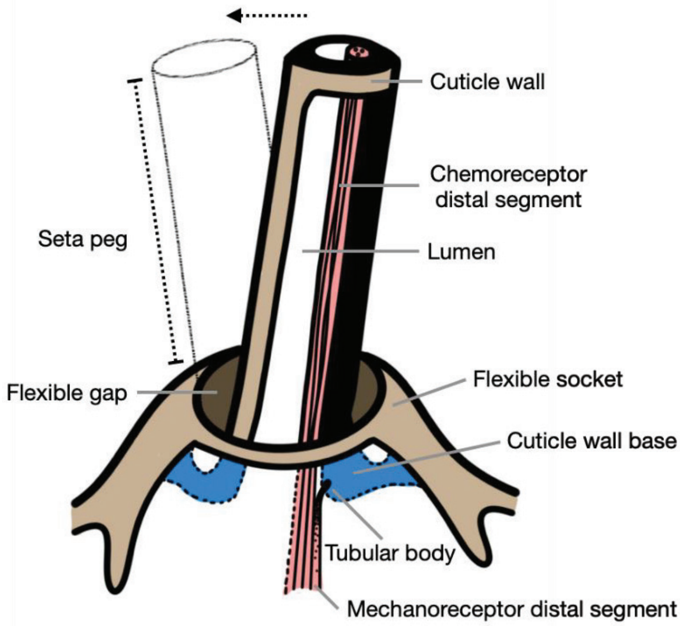

Fig. 3 The mechanism of cuticle distortion detection by tubular body in the base of cuticle wall (blue color). The sensillum peg may moves (dotted arrow) and occupies the flexible gap between the peg and the flexible socket. The cuticle distortion that caused by setae peg movement is sensed by the tubular body, the distal segment of mechanoreceptor (pink color) which is embedded in or placed close to the cuticle wall. Some flexible setae might also have chemoreceptor in the lumen that (pink color) elongated to the tip of the setae.

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O_06

Termite's elastic mandibles: conceptual modeling for mechanics

by

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Abstract

Elastic mandible snapping is the fastest biological movement known to date, and has been found in ants and termites. Pericapritermes nitobei termite soldiers have asymmetric elastic mandibles and can generate snaps up to 132 m/s. Before the snapping, Pe. nitobei solders use the right mandible to compress the twisted left mandible, during which elastic energy is stored in its two deformable "joints" at middle and base, respectively. To date, the detailed mechanism and functioning constraints of such "snap-jaw" system have not been thoroughly examined. In this study, we proposed a 2D models to simulate the elastic energy stored in mandibles with different geometries and compared the geometric features of models with optimized energy storage to the morphology of 45 extant termite species with asymmetric elastic mandibles. Our results show that the predicted mandible distance and relative length for optimal energy storage at the two joints are similar to those of extant species; however, the predicted relative position of left mandible's bending joint (i.e. the middle joint) matches the extent features only when the energy storage is optimized at its middle joint.

Key words: elastic mandible termites, biomechanics, functional morphology, geometric modeling, morphospace.

Introduction

Elastic energy storage and release allow the organisms to achieve high-speed movement beyond using muscles or other contractile cells. For example, some ferns eject the spores by dehydrating part of the tissue (Noblin et al. 2012); hummingbird beaks and flytraps close by flipping at different axes (Forterre et al. 2005, Smith et al. 2011); mantis shrimps strike their forelimb at 22 m/s using energy stored at its double-saddle structure (Patek et al. 2004) (Patek et al. 2011); trap-jaw ants close the mandibles at 64 m/s (Patek et al. 2006) by buckling the base (Booher et al. 2021). However, the fastest animal movements known to date almost come from the "snap-jaw" mechanism, by which elastic energy is stored in the deformed mandibles compressing against each other (Larabee et al. 2018, Kuan et al. 2020).

Snap-jaws present symmetric and asymmetric types. Symmetric elastic mandibles are found in some termites and ants that produce high-speed snapping: 67 m/s by *Termes panamaensis* (Seid et al. 2008), and 111 m/s by *Mystrium camillae* (Larabee et al. 2018). Asymmetric elastic mandibles have been reported only in termites and are suggested to evolve at least four times in Termitidae. However, only *Pe. nitobei* has been examined: our previous study showed that their mandibles can reach strike velocity of 132 m/s, which is the fastest known bio-movement (Kuan et al. 2020). However, the detailed functioning mechanism and constraints of the asymmetric elastic mandibular (snap-jaw) system have not been thoroughly examined.

To this end, we proposed a simplified two-dimensional model to computationally simulate the range of motion and elastic energy storage in asymmetric mandibles with different geometries, established the theoretical shape space (i.e. morphospace) of the mandibular system, and compared the results with extant species.

Materials and methods

Among the four independently-evolved termite groups with asymmetric elastic mandibles, all use the right mandible to compress and deform the left mandibles (Inward et al. 2007); therefore, we can set the model in the same frame of reference.

1. 2D mandible model

1.1. Definition of model. According to our study on *Pe. nitobei*, we first defined three pivot points that allow deformation: the bases of the right and left mandibles (P_{RB}, P_{LB}), and the middle bending point on the left mandible (P_M); an interfacial contact point (P_I) by the tips of the right and left mandibles exists during the compressing process, (Fig. 1A). Consequently, four segments can further be defined (Fig. 1B). Assuming no deformation, the range of segment motion can be predicted (Fig. 1C).

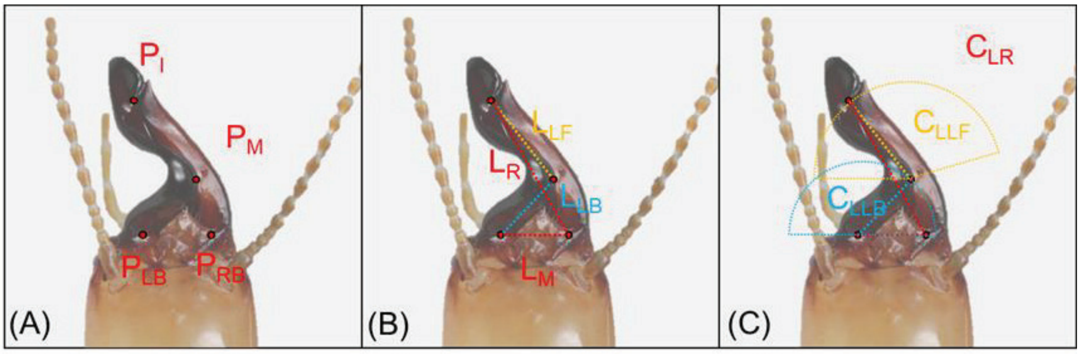

Fig. 1 Morphology and model definition of *Pe. nitobei* termite soldier's head and mandible. (A) Three pivot points and the interfacial contact of two mandibles; (B) Mandible segments; (C) Range of segment motion. P_{LB}, P_{RB}: middle point of the left and right mandible base, respectively; P_M: middle bending point of the left mandible; P_I: interfacial contact of two mandibles. L_M: distance between mandible bases; L_R: right mandible length; L_{LB}, L_{LF}: basal and fore segment length of left mandible, respectively. C_{LR}, C_{LLF}, C_{LLB}: Circle with radius L_R, L_{LF}, and L_{LB}, respectively.

1.2. Compressing process. The 2D model begins with the geometry of the resting state (Fig. 2A). Assuming no deformation, the contact tip (P_I) of the right mandible rotates about its base P_{RB} and undergoes a counter-clock wise circular motion (C_{LR}) with radius of its own length L_R ((Fig. 2B). To maintain compressing (i.e. two mandible tips in contact), P_M has to rotate counter-clock wise following C_{LLB} (Fig. 2C).

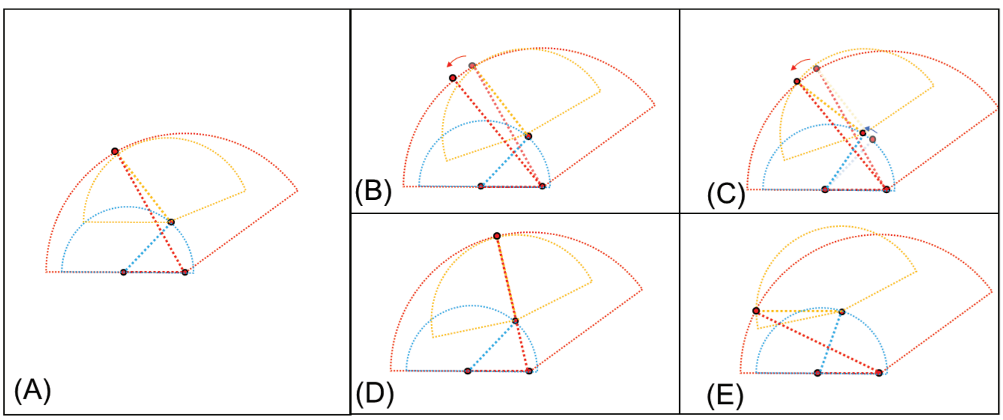

Fig. 2 Compressing process of the 2D geometric model for the asymmetric elastic mandible of *Pe. nitobei* soldier. (A) Geometry of mandibles at resting state; (B) Track of the right mandible tip during compression,

and the consequent track of the left mandible bending point (C); (D-E) Model's beginning and end of compressing, respectively.

1.3. Effective boundary. We determined the effective compressing range by investigating the relationships between the circular tracks of segment motion. Here we define the beginning of compression when circles C_{LR} and C_{LLF} inscribed (i.e. only one intersection) (Fig. 2D). When the right mandible undergoes counter-clock wise motion, intersection appears at the first and second quadrants, which lead to P_M and P_{LB} joint extension and compression, respectively (Fig. 2E). Based on empirical observation of *Pe. nitobei* soldiers, we only considered joint compression for modeling. To simplify simulation, the end of compression was defined when the L_{LF} segment becomes parallel to the L_M (Fig. 2E).

1.4. Normalization. To focus on the geometric effects of the mandibles and compare between species, we removed the scale effects by normalizing various lengths in Fig. 1B to that of the right mandible (L_R):

(1) Total length of the left mandible (L_L) equals the sum of the lengths of the fore and basal segments, and can be normalized to L_R by a factor R_L:

$L_L = L_{LB} + L_{LF} = R_L \cdot L_R$ (Eq. 1)

(2) The distance between mandible bases (L_M) can be normalized to L_R by a factor R_M:

$L_M = R_M \cdot L_R$ (Eq. 2)

(3) To examine effects of left mandible's geometry (i.e. the fore-basal segment proportion) on compression, we normalized its basal segment length (L_{LB}) to L_R by a factor R_B; its fore segment length (L_{LF}) can be calculated as:

$L_{LF} = L_L - L_{LB} = L_L - R_B \cdot L_R$ (Eq. 3)

2. Theoretical morphospace and elastic energy storage

2.1. Morphospace. Based on aforementioned definitions, we simulated the compressing process of the 2D mandible models using Python. Different conversion factors R_L、R_M、R_B were used to test whether the mandible contact P_I exists for given mandible geometries, so that the theoretical functioning morphospace of the asymmetric mandibles could be established.

2.2. Elastic energy storage. To evaluate the elastic energy storage for each condition, we assessed the outer joint angle θ_O (i.e. the angle between L_{LF} and L_{LB}) at the middle and the inner joint angle θ_I (L_{LB} and L_M) at the base of the left mandible. During mandible compression, the two joints undergo deformation of D_O、D_I, respectively, and were calculated as:

$D = |\theta^0 - \theta^1|$ (Eq. 4)

Compression of the asymmetric mandible is similar to that of torsion spring. Based on Hooke's Law (Collins et al., 2009), within the elastic regime the angular deformation θ of a torsion spring is in proportional to the torque (T) applied:

$T = k \cdot \theta$ (Eq. 5)

Subsequently, the work done to, and hence the elastic energy (U) stored in the two deformed joints can be calculated as:

$U = \frac{1}{2} T \cdot \theta = \frac{1}{2} F \cdot L \cdot \theta$ or $U \propto L \cdot \theta$ (Eq. 6)

Finally, we examined how mandible geometry affects the elastic energy storage by assessing joint deformation for left mandibles with varying relative size (R_L) and shape (R_B), and spacing between mandibles (R_M).

3. Elastic mandible morphology of extant termites

To examine whether the elastic mandibles of extant termite species have geometries for optimal energy storage, we compared their morphology with predictions from 2D modeling. We directly measured the relevant mandible dimensions of two Taiwanese species (*Pe. nitobei* and *Sinocapritermes mushae*) with asymmetric elastic mandibles and obtained the measurements from 64 termite species with elastic mandibles (22 species with symmetric type) reported in taxonomy literature (Krishna 1968, Constantino 1991, Scholtz et al. 2008, Almeida-Azevedo et al. 2021). Mann-Whitney pairwise analyses were done using PAST to compare morphological characteristics between mandible types.

While investigating the morphology of elastic mandibles, we found some asymmetric left mandibles have hook-like tip (e.g. *Si. mushae*), whereas some have hammer-like tip (e.g. *Pe. nitobei*). Therefore, previous two-typed classification (symmetric and asymmetric) for termite's elastic mandibles (Sands 1965) needs modification. To examine the functional morphology and mechanical consequences of elastic mandibles, we considered three types: symmetric hook-like (SHO), asymmetric hook-like (AHO), and asymmetric hammer-like (AHA).

Results and discussion

To link the function and form of elastic mandibles, we investigated the association of mandible symmetry and the tip shapes from 66 termite species directly measured or reported in the literature. Results show symmetric mandibles only have hook-like tips. Among 45 species with asymmetric mandibles (1 species with both symmetric and asymmetric forms), 27 species have hook-like left mandible tip, and 18 species have hammer-like ones. Therefore, we can classify termite's elastic mandibles into three types: symmetric hook-like (SHO), asymmetric hook-like (AHO), and asymmetric hammer-like (AHA). It is well accepted that the asymmetric mandible evolved from the symmetric form; therefore, hook-like mandible tip should be primitive trait. Subsequently, we can deduce that mandible's asymmetric form should evolve prior to existence of hammer-like tip.

Our results show that the predicted mandible distance and relative length for optimal energy storage at the two joints are similar to those of extant species; however, the predicted relative position of left mandible's bending joint (i.e. the middle joint) matches the extent features only when the energy storage is optimized at its middle joint.

Conclusions

In this study, we classified elastic mandibles, from functional and mechanical perspectives, into three types: symmetric mandible with hook-like tip (SHO), asymmetric mandible with hook-like tip (AHO), and asymmetric mandible with hammer like tip (AHA). Such results support previous hypothesis that asymmetric mandibles evolved from symmetric ones, followed by appearance of hammer-like mandible tip. The 2D geometric model we created for simulating mandible compression provides an opportunity to examine how geometry affects energy storage, and to assess whether extant termites have mandibles for optimal snapping performance.

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O_07

Overview of Termites damage to architectural works in Vietnam

by

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Abstract

Termite is pest of houses, dikes, dams, and crop plants in Vietnam. The history of research on termite control in Vietnam has only experienced 70 to 80 years, although the time is not too long, it also shows a rather complicated picture. Initially, it was the accumulated knowledge and experience from China, then the initial successes originating from the research results on the biological and behavioral characteristics of the main termite, the construction features of architectural works, dikes, dams or native crop plants. Termite control measures have also been developed from manual nest digging, termite repellent spraying, to chemical soil treatment, construction of a physical barrier, and later to general termite control in which bait is the key to effective termite control. Using chemicals to treat soil has been the standard treatment method for decades, but the concerns about human health and the environment have promoted the development of alternatives, which are the use of bait or preparations of biological origin. In this article, we introduce some published studies on termite control for architectural works in Vietnam from 1960 up to now in order to have an overview of the trend of termite control research that has developed over time and the supported viewpoints on termite control in Vietnam in the future.

Key words*:* termite, bait, integrated termite management, control termites

Introduction

Vietnam is located in a tropical climate zone, where conditions are favorable for termites (Isoptera) to develop. According to Nguyen Thi My et al (2021), there are currently 251 species, 45 varieties, 9 subfamilies and 4 families of termites have been recorded in Vietnam. This is the result of a general study of published documents on termite components in Vietnam from 1927 to January 2020. The number of termite species recorded in Vietnam is not much, but they cause significant harm to architectural works, dike and dam works and crop plants. In each group of species, the harmful nature and mode of termite control cannot be the same. The harms caused by termite to works in Vietnam have been mentioned quite early. In the historical documents of Vietnam, it is recorded that in about 1,000 years, from the end of the 10^{th} century to the end of the 19^{th} century, there were 188 years of water disasters, accompanied by a major disaster of dike breaking, that is, every 4 - 5 years, there is dike breaking due to termite. However, due to the war, like many other scientific fields, the research on termite in Vietnam has only started to develop since the 1960s of the 20th centuries. In this article, we introduce some published research on termite control for architectural works in Vietnam from 1960 up to now in order to have an overview of the trend of research on termite control over time and the supported viewpoints in termite control in Vietnam in the future.

The research on termite control in Vietnam develops in each stage and seems to depend on the time when there are reports on appearance of harmful termite species. Excluding the studies on species components and termite zones made in the early 20^{th} century by Bathellier (1927) on termite zones in Indochina with 19 species to be recorded in Vietnam and by Harris (1968) with 27 species to be recorded, the studies on termite in Vietnam, especially on termite control, have only been carried out since the 1960s, starting with prevention studies for the group of termites that damage architecture, followed by studies on termites that damage dikes and dams and in the next stage, they were studies on termites that damage crop plants. In this report, we only focus on the research on Termites damage to architectural works, while the studies on termites damage dikes, dams and crops will continue to be introduced in other reports in future.

Research on termite control for architectural works

Trinh Van Hanh et al., 2017, reported that there are 7 species of termites most commonly found in architectural works in Vietnam, they include the species *Cryptotermes domesticus, Coptotermes gestroi, Coptotermes ceylonicus, Odontotermes hainanensis, Odontotermes proformosanus, Odontotermes angustignathus and Odontotermes yunnanensis*, however, the author also added that this is a component of the harmful species to architectural works that are commonly found in urban areas, and in different landscapes, there may be some different harmful termite species. For example, Reticulitermes spp can be found in wooden houses in the high mountains of Vietnam.

With the components of identified species of termites, termite control is focused on 3 functional groups of termites related to their nesting environment, such as underground termites such as *Coptotermes*, and dry wood termites (e.g. *Cryptotermes*) and group of termites with fungal gardens (e.g. *Macrotermes* and *Odontotermes*). These groups of termites, based on their biological and ecological characteristics, are closely related to their control modes. Understanding the biological characteristics of the pest will be the key to help control them successfully. In the early years, the studies on controlling the termites damaging the architecture in Vietnam mainly focused on the group of underground nesting termites, namely *Coptotermes* group.

The studies on termite-harming architectural works in Vietnam officially started in the 1960s of the 20^{th} century. The publications about termites in this period mainly summarized works and applications of experience on termite control from China (Nguyen The Vien, 1961, 1964; Nguyen Chi Thanh, 1971; Nguyen Duc Kham, 1976).

From 1975 up to now, many methods of killing termites of the variety of Coptotermes have been mentioned by domestic authors with the research works of Nguyen Ngoc Kieng (1987), Nguyen Duc Kham (1976, 1985), Le Trong Son (1998), Nguyen Chi Thanh (1996), Nguyen Tan Vương (2005), Nguyen Tan Vuong et al. (2007), Trinh Van Hanh, (2008), Nguyen Minh Duc, 2021... This period is notable for the method of finding the nests for direct treatment of Nguyen Duc Kham and Vu Van Tuyen (1985) and the method of indirect killing of termites, without having to find the nests with the techniques of luring and spraying TM-67 or DM. -90 by Nguyen Chi Thanh (1996).

The method of killing termites of Nguyen Chi Thanh was developed on the basis of the method of "Direct infection in termite nests" of Ly Thuy My (1961) and the way of luring termites of Nguyen The Vien (1964), and also on the basis of science about the impact of sudden destabilization of the termite nest, the remaining population cannot restore the necessary balance state, leading to the destruction of the termite nest. This is a method applied mainly in Vietnam until the early years of the 21^{st} century. This method has the limitation that the success rate is low when termites are far from the nest and must use very toxic chemicals affecting to the environment.

The method of finding termite nests to kill directly by Nguyen Duc Kham and Vu Van Tuyen (1985) is based on receiving and amplifying the alarm signal of termites, when there is an impact from outside the termite nest, to detect the underground termite nests in architectural works. This method was widely applied in the 1980s of the last century. This method has the limitation that finding the nest takes a lot of effort and money, especially for works with complex structure, the cost of survey and treatment is high. At the same time, they still have to use toxic chemicals to treat termites, causing environmental pollution.

Nguyen Chi Thanh (1971) wrote the book "Termite control for construction works and treasure". Nguyen Duc Kham and Vu Van Tuyen (1985) wrote the book "Termites and termite control techniques". The content of the book provides important data on termite biology, fairly fully describes and standardizes the methods of termite control for construction works. Nguyen Chi Thanh (1994) revised and supplemented to produce the book "Termite control handbook", as a universal knowledge document for termite control. The doctoral thesis "Research on methods of killing and preventing termites without having to find nests for construction works" (Nguyen Chi Thanh, 1995) is considered as a summary up to this point of time on the harmful termites of architectural works in Vietnam, with a record of 25 species of harmful termites for architectural works and treasures in Vietnam.

From the early years of research until the early years of the 21^{st} century, the use of termite killing pesticides sprayed/mixed in the soil was the most commonly used primary termite treatment method and is still applied up to now. Before 2000, most of the termite treatment pesticides in Vietnam were not controlled by a specialized management agency and most of them used pesticides imported from China through the unofficial route. Until 1999, termite control pesticides were first listed in the List of pesticides allowed to be used, restricted from use, and banned from use in Vietnam (according to Decision 29/1999/QD-BNN dated 04 February 1999 of the Ministry of Agriculture and Rural Development), at this time only 3 types of active ingredients and 3 types of trade names have been registered. They were PMC 90 powder, PMs 100 powder and PMD4 90 powder all registered by Vietnamese Academy of Forest Sciences. A year later, one more pesticide was registered as Liquid M-4 termite control oil of the Vietnam Pesticide Joint Stock Company. The number of registered termite pesticides increased to 6 types of active ingredients with 06 trade names in 2004. Since then, every subsequent year, a few more companies operating in the field of pesticide products have joined in this field and many new pesticides were registered. Some types of soil termite treatment products used in Vietnam during this stage included: Termite pesticides: Na2SiF6 50% + HBO3 10%, Na2SiF6 80% + ZnCl2 20%, Sherpa (Cypermethrin), Lentrek 40 EC (Chlorpyrifos), Mapsedan (Chlopyrifos Ethyl), PMC 90 (Sodium Fluoride Silicate, Copper Sulfate, Boric Acid), Lenfos (Chlorpyrifos Ethyl), Termifos (Chlorpyrifos Ethyl) and a little later namely Termidor (Fipronil) (Table 1).

Table 1. The list of pesticides permitted to be used and banned from use in Vietnam.

Trade name	Active ingredient	Registration unit	Year			Stop register
			registration	limited use	forbidden to use	
PMC 90 power	Na_2SiF_6 50 % + H3BO3 10 % + $CuSO_4$ 30 %	Vietnammese Academy of Forest Sciences	1999			
PMs 100 power	Na_2SiF_6 80 % + $ZnCl_2$ 20 %	Vietnammese Academy of Forest Sciences				
PMD 4 90 bột	Na_2SiF_6 75 % + C_6Cl_5ONa 15 %	Vietnammese Academy of Forest Sciences		2003		
Termite Repellent Oil M-4 1.2 SL	Pentachlorophenyl 1% +Fenvalerate 1.2%	Vietnam pestidise joint stock company				+
Lentrek 40 EC	Chlorpyrifos Ethyl (min 94 %)	Dow AgroSciences B.V	2004			+
Kordon 250 TC	Deltamethrin (min 98 %)	Bayer Vietnam Ltd (BVL)				+
Backtop 15 MC	Fenobucarb (BPMC)	Sumitomo Chemical Co., Ltd.				+
Confidor 100 SL	Imidacloprid (min 99.6%)	Bayer Vietnam Ltd (BVL)				+
Lentrek 40 EC	Chlorpyrifos Ethyl (min 94 %)	Dow AgroSciences B.V	2005			+
Lenfos 50 EC		Brightonmax International Sdn Bhd, Malaysia			2019	
Baktop 15 MC	Fenobucarb (BPMC)	Sumitomo Chemical Co., Ltd.				+
Termidor 25 EC	Fipronil (min 97%)	Bayer Vietnam Ltd (BVL)			2011	
Dimez 1x 108 BTT/g	Metarhizium	Vietnammese Academy of Forest Sciences				+

MAP Sedan 48EC	Chlorpyrifos Ethyl (min 94 %)	Map Pacific Pte Ltd	2006			+
Metavina 10DP	Metarhizium anisopliae var. a nisopliae M2 & M5 109 - 1010 spores/g	Center for termite con trol research - Academy for Water Resources				
Metavina 80LS	Metarhizium anisopliae var. a nisopliae M1 & M7 108 - 109 spores /ml	Center for termite con trol research - Academy for Water Resources				
Metavina 90DP	Metarhizium anisopliae var. a nisopliae M1 & M3 109 - 1010 bào tử/g	Center for termite con trol research - Academy for Water Resources				+
Mythic 240SC	Chlorfenapyr	BASF Singapore Pte Ltd	2007			
Termize 200SC	Imidacloprid	Imp Biotech Sdn Bhd				+
Dursban 40 EC	Chlorpyrifos Ethyl (min 94 %)	Dow AgroSciences B.V	2008			+
Map Boxer 30EC	Permethrin	Map Pacific Singapore	2009		2019	
Termisuper 25EC	Fipronil	Branch of Vietnam Fumigation – Termite control joint stock company	2010		2019	+
Optigard TM ZT 240SC	Thiamethoxam	Syngenta Vietnam Ltd				
Agenda 25 EC	Fipronil	Bayer Vietnam Ltd (BVL)	2011		2019	
Terdomi 25EC	Fipronil	NgocLam investment and development company limited			2019	
Landguard 40EC	Chlorpyrifos Ethyl	Imp Biotech Sdn Bhd			2019	
Xterm 1%	Bistrifluron (min 95%)	Bayer Vietnam Ltd (BVL)	2012			
Requiem 1 RB	Chlorfluazuron	Ensystex Australasia Pty Ltd.				
Termifos 500EC	Chlorpyrifos Ethyl	Vietnam Pesticide Joint Stock Company			2019	
Wopro$_2$ 10FG	Extract of Cashew nut shell oil (min 97%)	Vietnammese Academy of Forest Sciences				
Fugosun 500EC	Chlorpyrifos ethyl	Asia agrochemistry company limited			2019	
Tefurin 25EC	Fipronil	Asia agrochemistry company limited			2019	
Sentricon	Hexaflumuron	Dow AgroSciences B.V	2017			

Bora care	Disodium Octoborate Tetrahydrate	Toan Dien Trading and services company limited				
Fugosin 500EC	Chlorpyrifos ethyl	HATASHI., JSC	2018		2019	
Mote 30EC	Fipronil (min 95%)	Asia agrochemistry company limited			2019	
Mobahex 7.5 RB	Hexaflumuron	Institute of Ecology and Works Protection				
Altriset® 200SC	Chlorantranilipr ole (min 93%)	Syngenta VietNam Compan y Limited	2019			
Ozaki 240SC	Chlorfenapyr (min 94%)	NgocLam investment and development company limited				
Wazaky 10 SC	Fenvalerate	Ct Sumimoto Việt Nam	2021			
Hunter 50EC	Imidacloprid	NgocLam investment and development company limited				
Imi noi 250 EC		Annong Group				
Mantra 305 SC		Ct Hóa sinh Vinchem				
Premise 200SC		Bayer Vietnam Ltd (BVL)				
Termise 200 SC		Imaspro Resoures				

In addition to chemical pesticides, there have been more studies on biological products to control termites. Nguyen Duong Khue et al. (2001) have studied how to use Metarhizium fungus for house termite control, however, the authors have only stopped at the level of testing the effectiveness of killing termites in the scale of the laboratory. Trinh Van Hanh (2007) introduced two types of biological products used in controlling termites harming the architecture, namely Metavina 90DP for termite treatment and Metavina 10DP for use as a pesticide mixed into the soil to prevent termites from entering the works. This can be considered as an important progress in the history of research on termite control in Vietnam. Registered in Vietnam for the first time, the termite control products were effective and friendly to the environment. However, due to high treatment cost, complicated storage and use conditions, these two products are not as widely used as some liquid termite pesticides registered at the same time.

In the 21st century, bait began to be studied as a preventive control method in new construction, instead of termite luring and treatment by powdered contamination pesticide. In 2004, Nguyen Tan Vuong et al. introduced the test results of a new type of termite bait called BDM 04. According to the author, this bait is highly effective against the termite of Coptotermes, which is the main pest for architectural works in Vietnam. The usage dose is 10 - 20g/nest and the effect of the bait is promoted for the period of about 15 - 30 days. However, the active ingredient used in this bait was later listed as banned from use in Vietnam.

In 2010, Institute of Ecology and Works Protection, one of the leading termite research units in Vietnam, introduced a type of bait named BDM 10 with active ingredient of Hexaflumuron that is highly effective against termites harmful to architecture and has been recognized by Plant Protection Department, Ministry of Agriculture and Rural Development as a scientific and technical progress. However, BDM 10 bait has limitation in durability when applied in the field, which can affect the efficiency of termite treatment, this bait has been improved and registered trademark at Intellectual Property Office of Viet Nam with the name of Mobahex. The components of Mobahex 7.5RB bait include mushroom powder A, bagasse powder, acacia powder, sugar and active ingredient of hexaflumuron (0.75%). According to the publication, the time to kill 50% (LT50) of bait at a dose of 0.3g/300 individuals is in 198 hours (ranged from 175-231 hours). The average amount of bait used for each works is 226g and the average treatment time is 39 days (Nguyen H.Y. et al, 2016). Mobahex 7.5RB bait efficiently kills termites and has more advantages than BDM10 bait that are easier to produce and take longer to have mould. The bait was issued the certificate of registration of pesticide by Plant Protection Department - Ministry of Agriculture and Rural Development (registration number: 6552/CNDKT-BVTV). Currently, Mobahex 7.5RB bait has been allowed by the Ministry of Agriculture and Rural Development to be used in Vietnam (in Circular No. 03/2018/BNNPTNT dated 09 February 2018 of the Ministry of Agriculture and Rural Development on the promulgation of the list of pesticides allowed to be used or banned from use in Vietnam). Also, during this stage, there were some baits introduced by foreign companies that were registered and used in Vietnam such as Exterm 1% (2012), Requiem 1RB (2012), Sentricon^{TM} HD 0.5 RB (2017), etc.

In 2007, Vietnam promulgated Vietnamese Standard TCVN 7958:2008 on protection of construction works - Termite control for new construction works. In the standard, there are regulations on requirements and methods of termite control applied to new construction works, using cellulose-containing materials as structures or containing and storing materials and documents with cellulose-containing components. This can be considered as the first legal document in Vietnam related to termite control for construction works, this standard was later reviewed and revised to TCVN 7958:2017 - Protection of construction works. Termite control for new construction works, in which it is worth noting that there are additional measures on termite control with a stainless-steel mesh system and termite control with a bait station system.

In 2014, Institute of Ecology and Works Protection was granted an exclusive patent of useful solution No. 1136 of Intellectual Property Office of Viet Nam (Ministry of Science and Technology) on 3 January 2014 for bait station and method of termite control for construction works. In which the bait station product has a structure with a wooden station shell, the wall of the cavity is coated with a waterproof layer, the bait is placed in the empty cavity and the mouth of the empty cavity is sealed with waterproof materials (paraffin, plastic, rubber). However, this product has the disadvantage that when it is placed in an environment with high humidity, the layer of wooden shell will be changed in dimension and quality, therefore, reducing the connection of the waterproof layer to the wall of empty cavity, causing peeling, crack of the waterproof layer, causing the bait to be waterlogged and damaged.

Overcoming the disadvantages of the previous bait station, Nguyen Tan Vuong researched, improved and introduced a new type of bait station with the structure as follows: cylindrical bait station shell is made of plastic, there is a cavity containing bait inside, surrounding the bait block is blocked with wood, sawdust, cotton or dried bagasse. The mouth of the cavity is sealed with a moisture prevention plug made of paper, plywood or cotton covered with a waterproof coating. The solution of bait station for termite control for construction works of Dr. Nguyen Tan Vuong was granted a patent of useful solution No. 2-0002931 by Intellectual Property Office of Viet Nam (Ministry of Science and Technology) on 25 June 2022.

On 12 February 2019, the Ministry of Agriculture and Rural Development promulgated Decision No. 501/QD-BNN-BVTV on the removal of pesticides containing active ingredients of Chlorpyrifos Ethyl and Fipronil from the List of pesticides allowed to be used in Vietnam, this removal has led to a strong shortage of termite control products in Vietnam. This has also led to a series of newly registered termite control products (mainly for soil treatment), which mainly focuses on the active ingredient of Imidacloprid with 5 new products in 2021.

It can be said that the research on termites harming to architectural works in Vietnam has achieved certain results, built efficient termite control processes, made practical contributions to the prevention of damage caused by termites in Vietnam. However, the problem of termite control in Vietnam still has many problems that need to be further researched. Because the efficiency of termite control depends a lot on the natural conditions of each ecological region; on technical level, equipment, people and economic ability of each place, therefore, the people doing the work of termite control in Vietnam are directing towards general termite control measures on a large scale similar to measures of general pest management or general pest control that have been applied in insect and pest control at present (Trinh Van Hanh et al., 2017).

Conclusion

The advances in research on the ecological and biological characteristics of termites have greatly supported the research and development of efficient products for termite control, however, the viewpoints and requirements of the house owners, works owners about the time of termite control has been a challenging issue for research on new termite control products.

There is no single treatment that is efficient for all areas and for all harmful termites. However, with the prospect of new development and improvement of existing termite control technologies, as well as acceptance of the public for the concept of general termite management, less toxic and non-chemical methods have been, are and will continue to be developed. In Vietnam, termite bait technology has been the target of scientists, especially baits for underground termites and then baits will play a major role in general termite control.

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Vietnamese Standard TCVN 7958:2008 Protection of buidings – Prevention and protection from termites for buildings under construction. (in Vietnamese).
Vietnamese Standard TCVN 7958:2017 Protection of buildings - Termite prevention for new building. (in Vietnamese).

Appendix 1.

Circular of Ministry of Agriculture and Rural Development about the list of pesticides permitted to be used in Vietnam and the list of pesticides banned from use in Vietnam:

+ Circular No. 29/1999/TT-BNNPTNT
+ Circular No. 33/2000/TT-BNNPTNT
+ Circular No. 17/2001/TT-BNNPTNT
+ Circular No. 16/2002/TT-BNNPTNT
+ Circular No. 53/2003/TT-BNNPTNT
+ Circular No. 15/2004/TT-BNNPTNT
+ Circular No. 22/2005/TT-BNNPTNT
+ Circular No. 31/2006/TT-BNNPTNT
+ Circular No. 94/2007/TT-BNNPTNT
+ Circular No. 49/2008/TT-BNNPTNT
+ Circular No. 32/2009/TT-BNNPTNT
+ Circular No. 24/2010/TT-BNNPTNT
+ Circular No. 46/2010/TT-BNNPTNT
+ Circular No. 36 /2011/TT-BNNPTNT
+ Circular No. 73/2011/TT-BNNPTNT
+ Circular No. 10/2012/TT-BNNPTNT
+ Circular No. 22/2012/TT-BNNPTNT
+ Circular No. 21/2013/TT-BNNPTNT
+ Circular No. 03/2015/TT-BNNPTNT
+ Circular No. 03/2016/TT-BNNPTNT
+ Circular No. 15/2017/TT-BNNPTNT
+ Circular No. 03/2018/TT-BNNPTNT
+ Circular No. 10/2019/TT-BNNPTNT
+ Circular No. 10/2020/TT-BNNPTNT
+ Circular No. 9/2021/TT-BNNPTNT
+ Circular No. 19/2022/TT-BNNPTNT

Decision No. 501/QD-BNN-BVTV of the Ministry of Agriculture and Rural Development promulgated on the removal of pesticides containing active ingredients of Chlorpyrifos Ethyl and Fipronil from the List of pesticides allowed to be used in Vietnam. (in Vietnamese).

Thursday | March 2, 2023 | 16:45-17:00

O_08

Improved heat treatment to mitigate heat sinks for drywood termite (Blattodea: Kalotermitidae) management in condominiums

by

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Abstract

The West Indian drywood termite, *Cryptotermes brevis* poses a significant economic threat in Hawaii, the southeast portion of the continental United States, and throughout tropical and subtropical regions worldwide. With heat treatments to control drywood termites (Blattodea: Kalotermitidae), the presence of heat sinks, which have insulating properties, causes heat to be distributed unevenly throughout the treatment areas. Drywood termites may move to galleries in heat sink areas to avoid exposure to lethal temperatures. Either a standard heat treatment performed by a heat remediation company, or improved heat treatment methods were performed in condominiums in Honolulu, Hawaii, that have *C. brevis* infestations in order to reflect real-world scenarios. For improved treatments, heated air was directed into the toe-kick voids of wooden cabinets to reduce heat sink effects. Thermistor sensors were placed inside toe-kick voids, in the treatment zone, embedded inside cabinets or the sidewall, or in a wooden cube to monitor internal and ambient temperatures to ensure sufficiently high heat reached all areas. Target temperatures above 46 °C or 50 °C were recorded in all areas throughout the 120-minute heat treatment period. A pretreatment inspection was conducted, and follow-up inspections were performed at 6 months posttreatment to confirm termite inactivity using visual observations and a Termatrac device. In improved treatment condominiums, no termite activity was found after treatment. Efficacious improved heat treatment protocols are proposed.

Key words: heat treatment; termite management; heat technology; pest management; drywood termite

Introduction

The West Indian drywood termite, *Cryptotermes brevis*, poses a significant economic threat in Hawaii and the southeast portion of the continental United States as well as throughout tropical and subtropical regions worldwide (Su and Scheffrahn, 1990; Scheffrahn et al., 1997a; Woodrow et al., 1999; Lewis et al., 2000; Su and Scheffrahn, 2000; Scheffrahn et al., 2009; Evans et al., 2013). Being recorded in Hawaii since 1884 (Bess, 1970) and as the most prevalent drywood termite species in urban environment, they cause serious economic losses and damage to structures.

Taking into consideration the risk of pesticides to human health, nonchemical or alternative strategies is commonly adopted in the management of urban pests (Tay 2022). Heat is an effective means of control for pests infesting structures and commodities (Hansen et al., 2011) and has been used against drywood termites, bedbugs, stored product pests, and powderpost beetles (Fields and White, 2002; Kells and Goblirsch, 2011; Lewis and Forschler, 2014; Suma et al., 2019).

The use of high temperature of 49 °C for drywood termite management was first documented by Forbes and Ebeling (1987). Scheffrahn et al. (1997b) reported that complete mortality was observed in the pseudergates of drywood termite species, including *C. brevis* when the internal wood temperature was maintained at 54.4 °C for one hour.

One of the challenges in performing an efficacious heat treatment is the presence of structural heat sinks or difficult-to-heat areas (Lewis and Haverty, 1996; Perry and Choe, 2020a; Tay and James 2021). A toe-kick, sometimes known as a toe space, is the recessed area between the bottom of a cabinet and the floor. This is a common design in kitchens and bathrooms and is a potential heat sink zone. Heat sinks require higher temperatures than other areas to heat the wood sufficiently to kill termites. This heat sink factor does not appear to have been thoroughly considered in developing protocols for heat treatment for drywood termite management in actual condominium units. This study investigated the efficacy of heat treatment with the aim of eliminating or reducing heat sinks by using a novel method.

Materials and Methods

The study took place in two (improved treatment) and three (standard treatment) residential condominium units in Honolulu, Hawaii. Honolulu is located on the tropical island of Oahu, Hawaii. *Coptotermes brevis* and fecal pellets were found in volunteers' condominium units, inside a few bases of the cabinets and inside the plywood countertop underlayment, and termite damage or infestation signs were reported at those locations. Using a low-energy microwave termite detection device, commercially known as Termatrac, three 10-minute inspections were performed to confirm termite activity and the locations of infestation in each condominium. The device was mounted on a tripod to minimize shaking, and all residents were absent during the inspections to reduce movement around the device. The numbers of spiked peak on the output's line graph in a 10-second period were photographed and recorded at the 10th minutes of each inspection. All factors that may generate false-positive results on Termatrac were considered following Taravati (2018). Heat treatments were subsequently conducted only in those parts of the condominium units (e.g., kitchens) with apparent termite activity. HI-Temp Tech, LLC., a Hawaii-based company that provides thermal remediation services, conducted the heat treatments.

Before the treatments, furniture, electrical appliances, and other items were moved away from infested areas as necessary to allow access for heat application. Air conditioners, air vents, and sink drains were covered and sealed with tape, and fire sprinklers were insulated. These steps improve heating efficiency, help hermetically seal the treatment zone. All cabinet doors and drawers were left in open and staggered positions.

Because the drywood termite infestations at these condominiums were associated with cabinets, the base cabinets with toe-kick voids were identified as the areas most prone to slow rates of temperature increases. For improved treatment condominiums, a four-inch-diameter hole was drilled in the back of each infested base cabinet with toe-kick voids (Fig. 1). For each condominium, a total of three thermistor probes were placed inside the toe-kick voids to monitor temperatures to ensure that the heat thoroughly reached all areas, including these heat sink areas (Fig. 2a). Two ambient air temperature sensors were placed at corners of the treatment zones. Two core temperature probes were placed by drilling to the center of the selected side cabinet (Fig. 2b). One custom-made wooden cube (9 cm^3) with an embedded temperature sensor in layered woods, which simulated the thickness of the cabinet wood but was made thicker than the actual cabinet wood to represent potential worst case areas, was placed in a cabinet for temperature recording (Fig. 2c). Temperatures from eight sensors were monitored from an online wireless portal (iMonnit, AZ, USA) in each condominium.

Fig. 1 Drilling of toe-kick voids in improved treatment condominiums, and a plastic cover designed to cover up the hole drilled at the bottom of cabinets after treatment for aesthetic reasons.

Electric heaters with distribution manifolds were used to generate and direct heated air into the drilled four-inch-diameter holes in the base cabinet's toe-kick via three-inch-diameter flexible duct pipes and into the rest of the treatment zone (Figs. 2a, d). Nine multiple high-velocity fans, designed to handle high temperatures were used. The fans were positioned in various angles to drive heated air into upper and lower cabinets and to create air currents to avoid air cavities and dead spots in the treatment zone (Fig. 2d).

Aluminized mylar blankets were placed as necessary to create hermetically sealed heat zones. This improves heating efficiency and reflects energy into the treatment areas. Safer electric heaters typically used for bedbug heat treatment were used together with fans. The heating protocols were adopted from current bedbug heat treatment protocols with some modification and improvement. In this study, once the target temperatures (50 or 46 °C) were reached in all voids and treatment areas, the heaters were continued for 120 minutes, and subsequently turned off. Heat was applied for a total of 165 minutes in the current study. The target temperature was achieved and maintained during the last 120 minutes before the heaters were turned off.

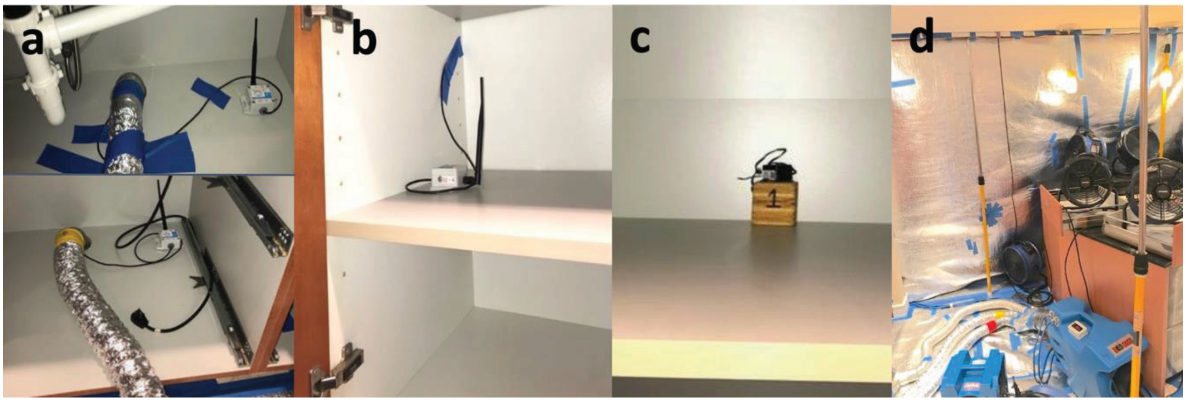

Fig. 2a In each improved treatment condominium, probes (right) were placed in toe-kick voids for temperature monitoring and recording. Flexible duct pipes (left; marked with blue or yellow cloth) were placed in toe-kick voids to direct heated air. **Fig. 2b** Core temperature probes were installed by drilling to the center of the selected sidewall or side cabinet, placing the probe in the hole, and sealing the hole with duct tape. **Fig. 2c** A custom-made wooden cube with an embedded temperature sensor was placed in a low-air circulation location for temperature recording. **Fig. 2d** Heaters (blue) and fans in place for heated air circulation.

For standard treatment (control condominiums), a heat remediation company conducted a typical commercial high-temperature treatments at three residential condominiums with similar treatment zone sizes and termite infestation levels. Similar heat treatment durations, temperatures, and rates of temperature increase were used. However, these treatments were performed without drilling holes in the back of base cabinets, without duct pipes to direct heated air into toe-kick voids. For standard heat treatments, the temperature sensors were placed inside the treatment zone, embedded inside cabinets or sidewalls, or placed in a wooden cube. The efficacy of the standard and improved heat treatments was compared at 6 months posttreatment by visual observation and using Termatrac, where the numbers of spiked peaks on the output's line graph in a 10-second period were photographed and recorded at the 10th minutes of each inspection. The data were square root transformed. The numbers of spiked peaks between pre- and posttreatment for each condominium were analyzed using paired t-test. The callback rates at 6 months posttreatment due to residents noticing termite pellets were also compared.

Results and Discussion

The results in this study would be applicable to condominiums with wood cabinets or furniture. In the improved treatment condominiums, the temperatures from eight wireless sensors showed that the temperatures recorded from the toe-kick areas were able to maintain an average above 50 °C throughout the treatment period. The core and ambient temperatures were maintained above 50°C, whereas the temperatures recorded from the custom-made thick wooden cube with an embedded temperature sensor remained above 46 °C. These temperatures are comparable to the original suggested treatment temperature of 49 °C (Ebeling, 1994), except the embedded temperature sensor in the cube with temperatures above 46 °C because it was made thicker than the cabinet wood to represent worst case scenarios.

To ensure treatment efficacy, one of the main factors that we must consider is the presence of heat sink areas (Perry and Choe, 2020a). These structural heat sink areas are commonly found in the wood contacting foundations or floors. A longer heating duration is required to reach the target temperature. Drywood termites tend to avoid high temperatures and may escape to these cooler zones in the wood and subsequently survive the heat treatment (Cabrera and Rust, 1996; Rust and Reierson, 1998; Cabrera and Rust, 2000). A laboratory study found that a temperature of approximately 49.6 °C for 2 hours is required to achieve complete termite mortality when considering the impact of a heat sink (Perry and Choe, 2020b).

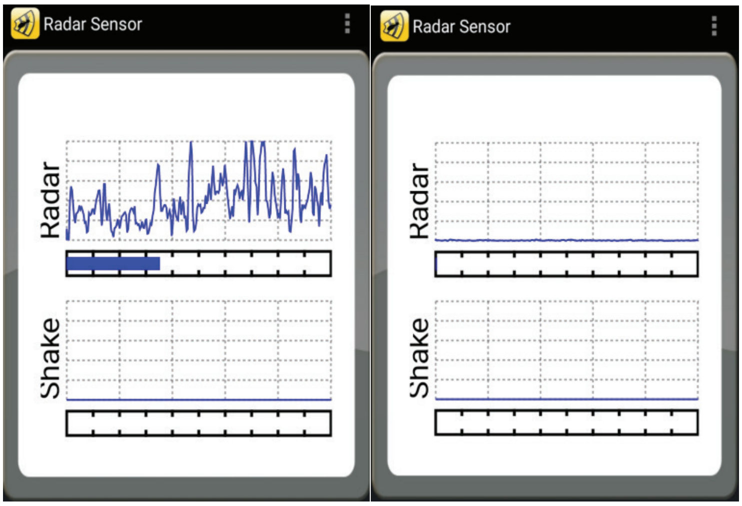

Fig. 3. Termite activity present pretreatment (left) and absent at 6 months posttreatment (right) in one of the improved heat treatment condominiums.

All our improved treatment condominiums and two out of three standard treatment condominiums had no termite activity at 6 months posttreatment according to Termatrac's spiked peaks on its output's line graph (Fig. 3) and visual inspections. In one of the standard treatment condominiums, no significant difference in the numbers of spiked peaks at the 10th minutes was recorded between pre- and posttreatment (pre-treatment: 8.33 ± 2.03; posttreatment: 5.67 ± 1.76; $t = 0.86$, $p = 0.48$), indicating that there were termite activity. Subsequently, a 33.33% callback (retreatment) rate was recorded in condominiums that underwent the standard heat treatment, as compared to a 0% callback rate in condominiums that underwent the improved heat treatment after 6 months.

Smith (1995) indicated that just a few surviving termites may lead to recovery and development of neotenic reproductives. Although drilling into toe-kick voids required more labor and a higher cost, this step ensured complete elimination of the termite colonies and reduced the need for additional treatments in the future. Additionally, if the temperatures of all target sites including heat sink zones (e.g., toe-kick voids) can be monitored following the proposed protocols for improved treatment condominiums, either the temperature or the duration of heat treatment may possibly be reduced, shortening the period during which the structure must be vacated and reducing the treatment cost and the potential for heat damage to household items and furniture.

Conclusion

When managing drywood termite, heat treatment may be the most preferable option when residents have chemical and/or environmental concerns. Heat treatment is also an attractive option for drywood termite-infested high-rise buildings, including condominium units, where fumigation is not feasible. This study was conducted in real-world residential properties using actual heating protocols that are currently used in typical heat treatments along with our own improvements and monitoring approach (e.g., a thick customized wooden cube embedded with a temperature sensor as an independent monitor and measurement of heat treatment effects). The approaches used and protocols developed were efficacious against *C. brevis* in this study.

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Thursday | March 2, 2023 | 17:00-17:15

O_09

Long-term effects of baits on the foraging activity of a fungus-growing termite, *Odontotermes formosanus* (Blattodea: Termitidae)

by

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Abstract

Fungus-growing termites facilitate carbon recycling process in tropical and subtropical forests by consuming leaf and woody litter on the ground. Application of termite baits in forests suppresses the population of fungus-growing termites and may have a long-term effect on termite population in forests. To understand the long-term effect of baiting, we measured the monthly foraging activity of *Odontotermes formosanus* (Shiraki) in a tropical forest previously treated with hexaflumuron termite baits. The results showed that foraging activity of *Odontotermes formosanus* significantly decreased after baiting, and gradually recover after removal of termite baits. Analysis of multiple regression model shows that foraging activity constantly increased per month within two years after the removal of termite baits.

Key words: Fungus-growing termites, *Odontotermes formosanus*, termite bait, population reconstruction.

Introduction

Fungus-growing termites (Blattodea: Termitidae: Macrotermitinae) are majorly distributed in tropical and subtropical regions of Africa and Asia (Krishna et al., 2013). Fungus-growing termites construct subterranean gallery system and build the soil-sheeting to forage on leaf and woody litters in the forest (Inoue et al., 2001). They play an important role in the decomposition of litter, for example, fungus-growing termites were reported consuming 90% of litter in Kenya and 60% of litter in Nigeria (Buxton, 1981; Collins, 1981).

Fungus-growing termites were also reported attacking a variety of crops and orchards in Africa and Asia (Rouland-Lefèvre, 2010). Most effective insecticides for controlling fungus-growing termites were not prohibited due to their damage to environments and non-target animals (Huan et al., 2016; Kathage et al., 2018). Recently, Chiu et al., 2022 found that hexaflumuron durable baits could effectively suppress a population of fungus-growing termites in the forest. However, how long will the termite baits affect the termite population in the field has never been examined.

Odontotermes formosanus (Shiraki, 1909) is a fungus-growing termite widely distributed at altitude 0–1,600 m in Taiwan (Yang and Li, 2012; Wu and Li, 2020). The foraging activity of *O. formosanus* is seasonal and affected by temperature and rainfall (Chiu et al. 2018). In this study, we aim to understand the long-term effect of baiting on foraging activity of *O. formosanus* in the forest. We measured the foraging activity of *O. formosanus* in a tropical forest previously treated with termite baits, and analyzed the termite population variation per year.

Materials and Methods

Experiments were conducted in a long-term study site in Xiaping Tropical Botanical Garden of the Experimental Forest, National Taiwan University, Nantou, Taiwan. In the study site, four study plots (50 × 50 m) with a total of 484 wood stakes (30.5 × 5.5 × 1.5 cm; *Pinus radiata*) were established for monitoring termite foraging activity since January 2013 (Chiu et al., 2016; Chiu et al., 2018). Wood stakes in each plot were installed with a 5-m interval, and there were 121 wood stakes (11 × 11) in each plot. The occurrence of termites on wood stakes was recorded monthly, and the wood stakes with >50% wood consumption were replaced. Since September 2017, nine Recruit HD termite baits (Noviflumuron, Dow AgroSciences, 2011) were installed in each plot with a 15-m interval (Chiu et al., 2022). All of the baits were consumed or removed before December 2019.

Monthly termite foraging activity was analyzed using a multiple regression model. The number of wood stake occupied by termites is considered as dependent variable, and number of months after baiting, minimum pressure per month, average temperature per month, maximum and minimum temperature per month, number of precipitation day per month are consider as independent variable; using in the stepwise regression analysis.

Results and discussion

A total of 82 monthly monitoring data were obtained, from January 2016 to October 2022 (Fig. 1). The average number of wood stakes occupied by termites per month before baiting (2016 and 2017) were 34 and 36; both years had highest occupation number in January (59 and 64), and lowest occupation in August (18 and 12). The average number of termite occupation per month during baiting (2018 and 2019) were 26 and 18. The number of termite-occupied wood stakes per month was highest in January (41), lowest in May (11) in 2018, and highest in December (34), lowest in March (2) in 2019. The average termite-occupied wood stake number per month after removing termite baits (2020 - 2022) were 28, 24, and 31. In 2020, the occupation number was highest in December (29) and lowest in July (12); in 2021, were January and June (49 and 7); in 2022, were January and August (50 and 16). These results showed that termite activity constantly reduces between the baiting duration (2017 - 2019) and increases after the removal of the termite baits (2020 - 2022) (Fig. 2).

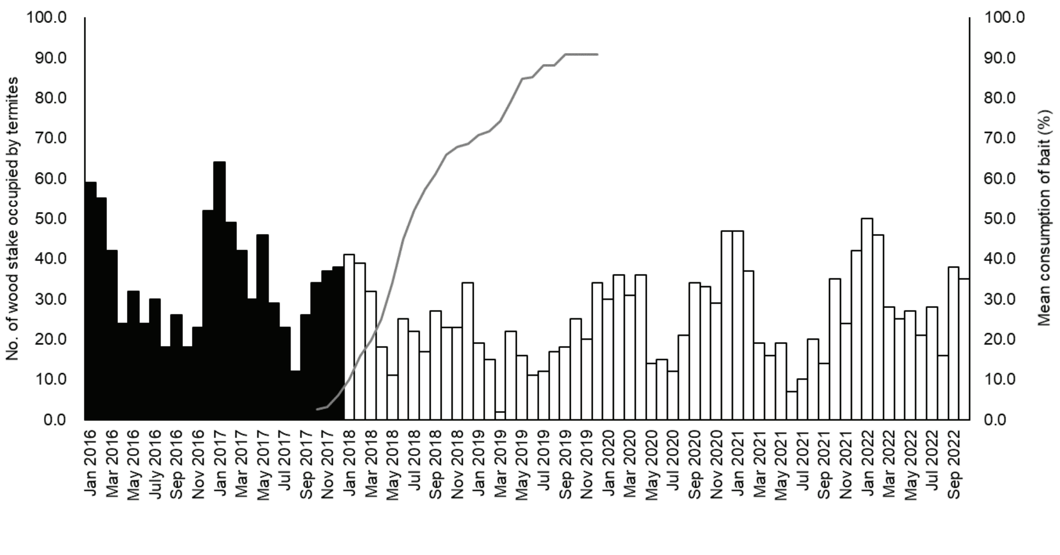

Fig. 1 The number of wood stakes occupied by termites per month before and after baiting. Termite baits were given from September 2017 to December 2019. The black bar is before baiting, the white bar is after baiting, the gray line is the average consumption of termite baits (%).

Results of the multiple regression model (Table 1) show that termite foraging activity was negatively correlated to rainfall and temperature, which is consistent with the observation of Chiu et al. 2022. Termite foraging activity was positively correlated with the number of months after baiting, which indicates that the termite population gradually recovered after baiting. The maximum, minimum temperature, and minimum pressure per month are not significantly related to termite foraging activity. Based on this result, the termite population is still not completely rehabilitated within three years after baiting.

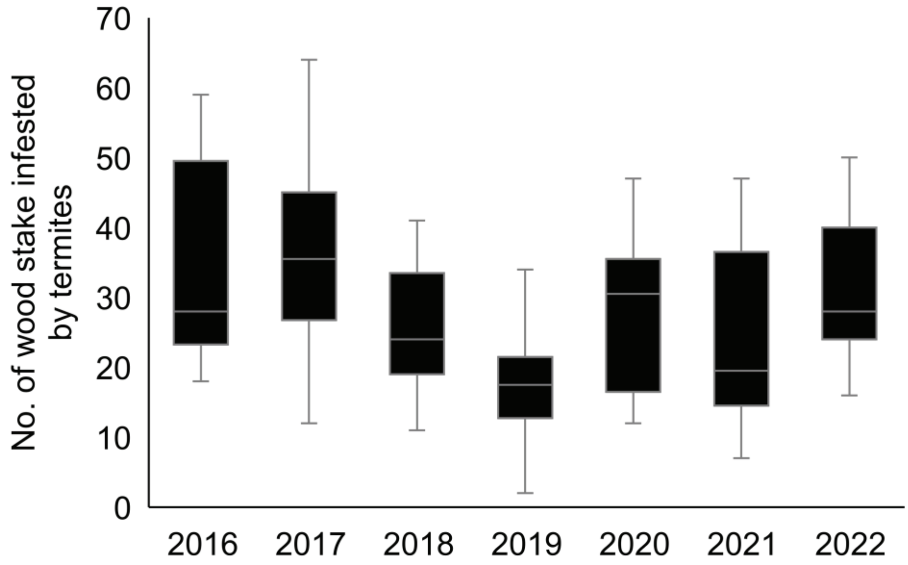

Fig. 2 Number of wood stakes occupied by termites per year, from January 2016 to October 2022. Termite baits were given from September 2017 to December 2019.

Table 1. Result of stepwise regression model analysis, with number of wood stake occupied by termites per month after baiting from January 2020 to October 2022.

Dependent variable	Estimate	Std. Error	t value	Pr (> | t |)
(Intercept)	918.675	424.314	2.165	0.047 *
Number of months after baiting	0.926	0.219	4.227	0.001 ***
Minimum pressure per month	-0.844	0.429	-1.965	0.068
Average temperature per month	-6.577	1.775	-3.706	0.002 **
Maximum temperature per month	1.816	1.336	1.359	0.194
Minimum temperature per month	1.952	1.033	1.890	0.078
Number of precipitation day	-0.519	0.220	-2.359	0.032 *

Conclusions

Treating termite baits to fungus-growing termites would cause a reduction on foraging activity of termite. After removal of termite baits, the termite foraging activity is unable to recover within three years.

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Thursday | March 2, 2023 | 17:15-17:30

O_10

Laboratory trials for testing innovative anti-termite barriers: Assessment with different termite species

by

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Abstract

Physical barriers are a rational option for termite management in the building sector. Biocide free, they offer an eco-friendly, non-invasive option to protect buildings and its assets from subterranean termite degradation. The development of such barriers needs to stand on reliable laboratory tests as a first evaluation step. This paper presents a laboratory test method to assess the efficacy of innovative physical anti-termite barriers, previously been shown reliable and reproducible with *Reticulitermes flavipes*. It has been therefore extended against *Coptotermes* to compare termite behavior and product performance.

Key words: *Reticulitermes*, *Coptotermes*, physical barrier, laboratory methodology

Introduction

Considering the global expansion of termite as a pest, the increasing use of wood and wooden-products, the increased scrutiny of biocide use, newer regulations, and the general public expectations, physical barriers represent a major sustainable way to be part of efficient termite management systems (Govorushko, 2019; Oi, 2022). Physical barriers as alternatives to termiticides are available in various forms, such as particle size barriers, mesh, (plastic) films (Ahmed and French, 2008). During their early development phases, these barriers must be laboratory assessed for their efficacy, to allow discriminant responses in a decision-making scheme. Even if laboratory tests can be considered as questionable as they are short-term and are only a partial representation of what happens in real situations, they overcome the unpredictability of field tests and termite population behaviors (Su et al, 2004)

Thévenon et al. (2020) have developed an easy and reliable laboratory method to evaluate films or mesh resistance towards *Reticulitermes flavipes*. However, due to unique strategies and foraging behavior, the wide range of wood-destroying termites create a very large potential for damage, and some termite species such as *Coptotermes* have been shown to be more aggressive than *Reticulitermes* (Lenz et al., 2013). Therefore, the aim of this paper is to test the developed laboratory method to *Coptotermes* species to compare barrier performances.

Materials and methods

Two physical barriers were tested: (A) a 100% bio-based polyamide film, (D) a mesh made of bi-component multi-filament polyester yarn which has sheath end core part each filament, the grid pattern presenting holes of 0.63 mm^2.

Each barrier was cut into 6 cm^2 samples with no preferential side. Film A was tested: (i) as it was (undamaged) for both *R. flavipes* and *C. gestroi*, or (ii) with 4 small holes of 0.5 or 0.7 mm, drilled using 25G and 22G needles respectively for *R. flavipes* only. The holes were bored at the corners of a 1cm^2 square, at the center of each film sample (Fig. 1). Barrier D, being already a mesh, was used only in its original form. The barriers are then placed in between glass tubes (5 cm height and diameter), as presented in Fig. 2 and 3. In the control devices, the barrier was replaced by a thermoplastic film (Parafilm®, Sigma). A pine (*Pinus sylvestris*, L.) sapwood bait of dimensions 15x25x25 mm^3 (L,R,T), covered by wet Fontainebleau sand (4 vol sand /1 vol deionized water), is placed in the lower tube. Six hundred (600) termite workers (plus 6 nymphs and 6 soldiers for *R. flavipes* or 60 soldiers for *C. gestroi*) were introduced on the upper compartment containing humid floral foam.

Fig. 1 Film drilled

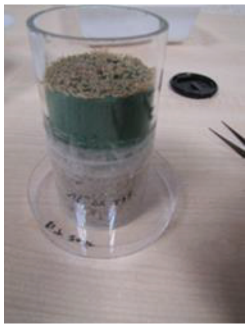

Fig. 2 Test device

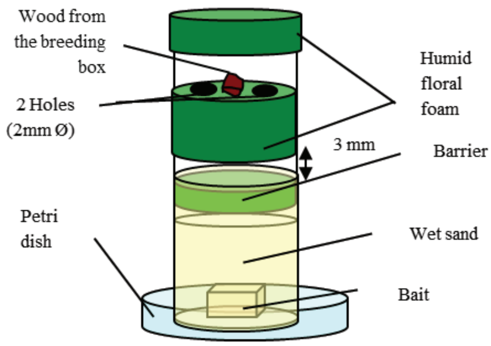

Fig. 3 Scheme of the test device

Each modality (barrier with/without holes) were tested in four replicates. The test devices were kept 8 weeks (i) at 27°C, 75% Relative Humidity (RH) for *R. flavipes*, (ii) at tropical ambient conditions (La Réunion island) for *C. gestroi*. At the end of the test, the survival rate of the termites is calculated, a visual rating is given to each Pine bait (based on the visual assessment of the EN117) (EN117, 2013) and once dried at room conditions, the barriers, or the Parafilm®, are observed.

As a comparison, an additional test was performed on barrier D, according to the Japanese standard JWPAS-TS-(1) (Japanese wood preserving association, 2018) using 200 *Coptotermes formosanus* workers, Cryptomeria japonica sapwood bait (Fig 4), and was left 22 days at 28°C, 80% RH.

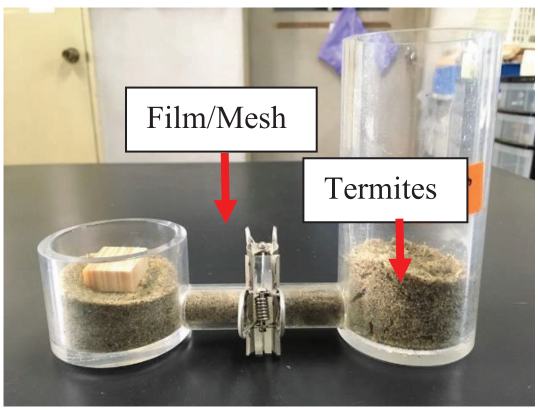

Fig. 4 Test device for *Coptotermes formosanus* (JWPAS-TS-(1))

Results and discussion

The results with *R. flavipes* and *C. gestroi* are presented in Table 1. For all controls, over 50% of the termites were found alive, the Parafilm® was observed to be heavily damaged and the bait presented a severe attack, which validated the test in terms of (i) sufficient termite pressure and (ii) food source palatability and availability for both species (Fig 5).

Barrier A performed well as only nibbling was noticed (Fig. 6), with small holes acting as primer for *R. flavipes* penetration (Thévenon et al., 2020). Film A was shown resistant to *C.gestroi* in this test configuration (no holes) (Fig. 7).

Table 1. Performances of the physical barriers towards *R. flavipes* and *C. gestroi*

Barrier	Treatment	Barrier observation	Pine bait Visual rating	Termite survival rate (%)
Reticulitermes flavipes				
A	-	No degradation, no material removal from the film, nibbling signs on few samples	0*	0
	4 holes, 0.5 mm Ø	No degradation even around the holes, no material removal from the film, nibbling signs on few samples	0	0
	4 holes, 0.7 mm Ø		0	0
D	-	No degradation, no material removal from the mesh	0	0
Controls	16 samples	Degradation of the Parafilm® used as a control barrier, crossing of the film	4**	Higher than 50%
Coptotermes gestroi				
A	-	No degradation, no material removal from the film, nibbling signs on few samples	0*	26
D	-	For 3 samples: No degradation, no material removal from the grid	0	32
		For 1 sample: Degradation of the grid	4**	50
Controls	8 samples	Degradation of the Parafilm® used as a control barrier, crossing of the film	4	Higher than 50%

(*No attack, **Severe attack)

The pattern holes of grid D are too small to allow the termite go through, and *R. flavipes* did not degrade the mesh (Fig. 8), but in one of the 4 samples, *C. gestroi* did degrade the mesh to access the bait (Fig. 9). When grid D was exposed to *C. formosanus* (JWPAS-TS-(1) test, Fig. 4), the termites did not damage the barrier and could not reach the bait within the 22 days of exposure.

This test method was shown to be discriminant for different film products tested with *R. flavipes* (Thévenon et al., 2020). In this case, it was considered mandatory to damage the films with holes acting like primer failures, which would allow workers to initiate a foraging on these weak points of the film. In the case of *C. gestroi*, the films do not need this pre-treatment, especially when a high number of termites is used, due to their higher aggressiveness (Lenz et al., 2013). The performances of different plastic films towards *C. formosanus* was not clearly changed whether they were used aged by sanding (scratched) or undamaged (Tsunoda et al., 2010).

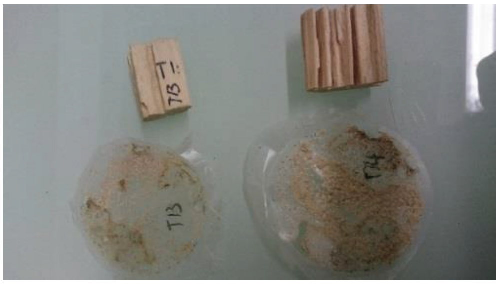

Fig. 5 Controls film and baits

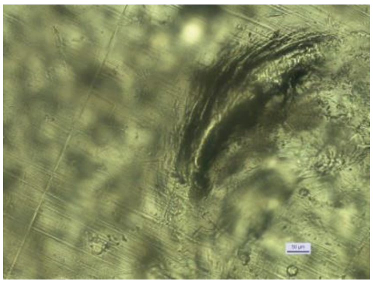

Fig. 6 Nibbling on film A

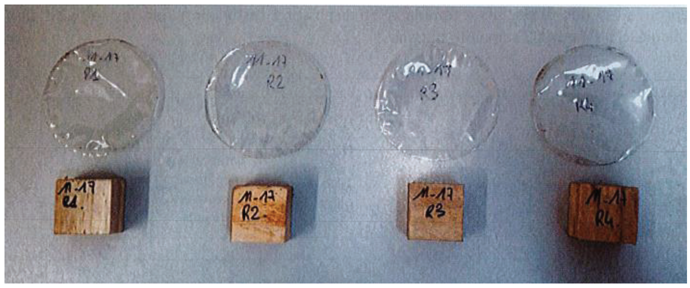

Fig. 7 Film A undamaged by *C. gestroi*

The high *C. gestroi* pressure (600 workers) is adequate with regard to the palatability and the size of the Pine bait as the controls present a survival rate above 50% along with a strong degradation of the wood. For the devices where the films (A or D) were not damaged, the survival rate of *C. gestroi* (above 25%) suggest that the termite activity was maintained during the whole 4 weeks exposure, which is not the case for the *R. flavipes*, stressing once again the differences in termite resistance. The termite pressure in these tests is 30.6 workers/cm^2 of film surface, higher than the preferential pressure (24 workers/cm^2) defined by Tsunoda et al. (2010) when testing high density polyethylene (HDPE) films with *C. formosanus* in a JWPAS-TS-(1) (Japanese wood preserving association, 1992) test configuration. A higher pressure of 40 termites/cm^2 did not lead to a higher film degradation due to overcrowding in the small space of the device.

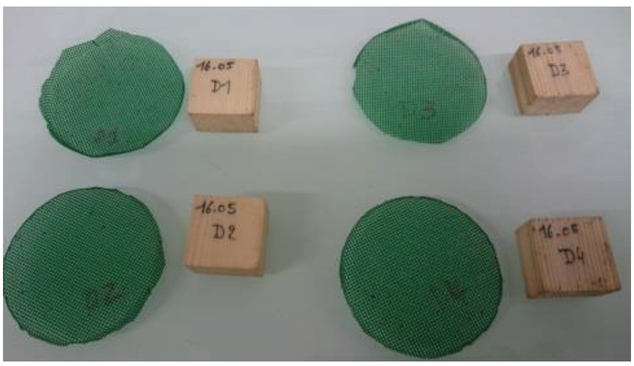

Fig. 8 Undamaged grid D and baits, *R. flavipes*

Fig. 9 Damage on grid D, *C. gestroi*

The additional test using JWPAS-TS-(1) method with 200 workers did not show any damage on film D. This result is comparable to what was obtained by Tsunuda et al. (2010) using 150 workers to test HDPE films. Therefore, for a complete comparison and to be able to adopt this test to *C. formosanus*, it would be important to set up our test method using 24 and 30.6 workers/cm^2, to check if the device itself (vertical instead of horizontal in the Japanese standard) is of importance, and what is the most adequate pressure considering the termite biology.

Conclusions

The laboratory method developed to test anti-termite barriers is reliable and discriminant when using *R. flavipes*, as long as a pre-treatment made of drilled holes in the film is done. This method can be used for *C.*

gestroi, but in this case, pretreatment is not compulsory. The number of termites used (600 workers) is adequate to bring enough biological pressure to challenge the films in the test. More development is needed to state whether this method can be reliable with *C. formosanus*.

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Friday | March 3, 2023 | 09:00-09:15

O_11

Features and applications of an automatic system for monitoring termite activity using DEKAN electromagnetic induction with non-looping method and LoRa communication

by

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Abstract

Monitoring termite activity plays an important role in termite management. Here we described an automatic wireless systems for monitoring of termite activities based on DEKAN electromagnetic induction with non-looping (short as DEMINL) method and LoRa Communication. We have developed a fully automatic system, which consists of a termite monitoring station, an information concentrator (Gateway), a network server and a PC-end management monitor. LoRa technology was used for signal transmission between termite monitoring station and information concentrator. The electronic components in the device are completely encapsulated for water resistance. Field tests have showed the device based on DEMINL and LoRa technology has high accuracy and durable characters in detecting of termites.

Key words: termites, automatic, DEMINL, non-looping, electromagnetic, LoRa

Introduction

Wood-feeding termites are notorious pests of forestry, agriculture and buildings that cause billions of dollars per year. To control the spread of termite species, a vast array of strategies have been developed. For the termite infested area, insecticides such as Neonicotinoids, aryl pyrrolidines, and insect growth regulators (Hexaflumuron, diflubenzuron, and novaluron) are used as bait or liquid aerosol strategy (Chiu et al. 2022; Su and Scheffrahn 1998; Lewis and Forschler 2010). Other environment-friendly materials including entomopathogenic fungus (Ambele et al. 2020), RNAi treatment (Mogilicherla et al. 2022), and physical management strategies (electrocution, microwave etc.) (Ahmad et al. 2021) are also performed. For the non-infested area, insecticides and various plant-based extracts can be use as repellents as well (Appalasamy et al. 2021; Asiry, Abir, and Abohassan 2022).

The effectiveness of termite control is still limited by one bottleneck factor: how to detect termites underground precisely. Pest termites, especially subterranean termites including genus *Coptotermes*, *Reticulitermes*, and *Odontotermes* can nest underground of wooden structures, reservoirs, dams, and dykes area (Su and Scheffrahn 2000). It is hard to detect their colonies. To overcome this problem, a monitoring and bating system has been developed. The baits consisting of cellulose, insecticides, wood materials or additional pheromones are placed underground (Carnohan, Lee, and Su 2021). Foraging workers discovered the bait could guide their nestmates to the toxic baits and hence spread the insecticides to the whole colony. This efficient system was further upgraded to automatic electronic devices that able to detect the existence of termites. To date, termite monitoring stations equipped with diverse detectors (odor, acoustic, and infrared detectors etc.) have been used for prevention and management of termite infestation (Lax and Osbrink 2003;

Wright et al. 2009). It is possible to monitor termites with a lower labor cost and save considerable time via the automatic detection methods. We designed a monitoring system based on the DEKAN electromagnetic induction method with non-looping (DEMINL) and LoRa technology, which meet the criteria of high accuracy rate and low labor cost.

How does it work?

The system constitutes of four parts (Fig. 1) – monitoring device, signal concentrator (gateway), a network server and PC or cell phone monitor. This system is made based on DEMINL and LoRa technology. In a termite monitoring device, while the wood pieces in the bait station were consumed by termites, the device could generate alarm signals based on DEMINL technology, which was invented by DEKAN Company. These signals were then sent to a signal concentrator or gateway based on LoRa communication.

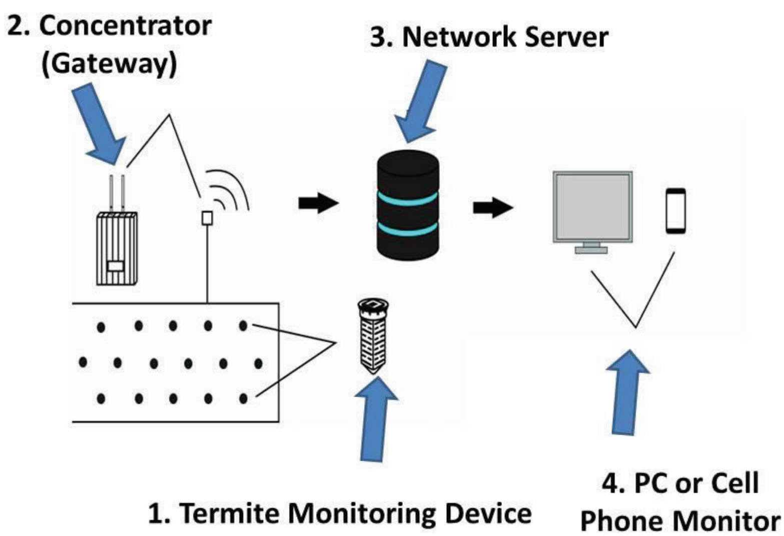

Fig. 1 An automatic termite-detecting device constitutes four parts: termite monitoring device, concentrator (gateway), network server, and PC or cell phone end monitor.

Practical applications

This automatic termite monitoring system has been applied at more than 100 locations since 2018. In general, the accuracy rate is over 95%, which shows its high accuracy and durable character in detecting termites. Here we reported three representative sites for the detailed parameters of our devices.

1. Siming Lake Reservoir

Siming Lake Reservoir is located in Yuyao, Zhejiang Province, China. SiMing Lake Reservoir owns 1,878 surface acres with average water depth of 53.4 feet. The dam of this Reservoir was built across the Yaojiang River. It is a concrete arch gravity structure 68.9 feet high and serves to store water from the upstream of Yaojiang River. Beneath the dam floor growing a large number of trees that seriously damaged by termite of genus *Reticulitermes* and *Odontotermes* (observed since 2018). The dam is highly threatened by these flourished subterranean termite colonies.

We deployed our automatic termite monitoring device at the forest area along the SiMing Lake dam, which already severely damaged by termites (Fig. 4, A to G). The spot with alarmed bait devices was checked and subsequently opened manually to observe the termite activity inside and the status of the device. If amount of termites were observed in the device, insecticide treatments were performed. We did a follow-up survey about the performance of the monitoring system.

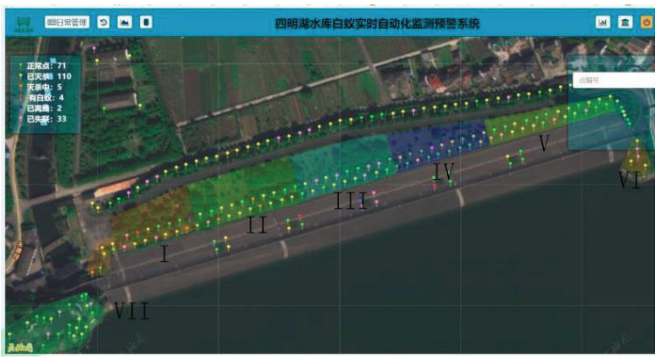

Fig. 2 Scheme of termite monitoring devices deployed along Siming Lake Reservoir.

Fig. 3 Different colors stand for various statuses in termite monitoring devices.

Fig. 4 Termite damages along SiMing Lake Reservoir. A-G, Termite mud tubes on trees below SiMing Lake dam. H, Termite monitoring devices. I-L , Mud observed in devices.

We extract the alarming data from the termite management database installed in SiMing Lake Reservoir Center Station. Together with our random checking of the deployed devices (Fig. 4, H-L), we calculated the performance of our automatic devices in SiMing Lake Reservoir project as methods described by Su (2001):

TN (true negative), information bar is intact (no alarm) and absence of termites; **TP (true positive)**, alarm signal (red spot) and observed termites inside the bait device; **FN (false negative)**, no alarm signal received but the devices were destroyed; **FP (false positive)**, alarm signal (red spot) but absence of termites.

Two categories of accuracy rate including accuracy rate (AR)% and accuracy rate of positive signals (ARP)% are hence calculated as follow:

Accuracy rate (AR)% =(TN+TP)/(TN+TP+FN+FP) *100%. Accuracy rate also represents the integrity (longevity) rate of device, which can be used to evaluate the durable character of the device.

Accuracy rate of positive signals (ARP) %=TP/(TP+FP).

Table 1 Performance of automatic termite monitoring system at SiMing River Reservoir

Site	Year	TN	TP	FN	FP	AR%	ARP%
Yuyao, SiMing Lake Reservoir	2020	23	17	0	2	95.2	89.5
	2021	21	17	2	0	95	100

The result indicated that automatic termite monitoring system showed a high accuracy rate during the 2-year survey at SiMing Lake Reservoir. In 2020, the accuracy rate is 95.2%, only two among the 42 bait devices sent false positive signals, no false negative device found in this year. At 2021, we observed two false negative device and no false positive signal received among the 40 checked devices. The accuracy rate of this year is 95% and accuracy rate of positive signals is 100% (Table 1).

2. Xiling Seal-Engraver's Society

Xiling Seal-Engraver's Society was founded in 1904 with various famous Chinese carving calligraphy, paintings, and art collections. It is located in Hangzhou, Zhejiang Province, China. Xiling Seal Engraver's Society is also a national key cultural relics protection unit. This area has a number of wooden heritage buildings. Termite mud was observed during the repair and rehabilitation of wood buildings.

Fig. 5 Scheme of termite monitoring devices applied in Xiling Seal-Engraver's Society

During the rehabilitation program, we deployed 468 automatic termite detecting devices in this area. Up to November 2022, we collected the alarming messages and calculated the performance of our devices. All deployed devices were checked manually about the termite activity. During the manually checking process, we identified two distinct subterranean termites in this area: *Coptotermes formosanus* (67 spots), and *Odontotermes formosanus* (9 spots) damaging wooden buildings and trees.

Our result depicted that among the 468 automatic devices we applied in Xiling Seal-Engraver's Society, only three devices sent false signals (FP) or not alarmed (FN). We obtained a final accuracy rate of 99.3% in this area, and 98.6% of accuracy rate of positive signals (Table 2).

Table 2. Performance of automatic termite monitoring system at Xiling Seal-Engraver's Society and the Chen Chan Academy

Site	Year	TN	TP	FN	FP	AR%	ARP%
Xiling Seal-Engraver's Society	2022	392	73	2	1	99.3	98.6
The Chen Clan Academy	2022	126	20	4	3	95.4	88.0

3. The Chen Clan Academy

The Chen Clan Academy is an academic temple in Guangzhou, China, built by the 72 Chen clans for their juniors' accommodation and preparation for the imperial examinations in 1894 in Qing Dynasty. The Chen Clan academy is notable for the rich decorations which makes the Chen Clan Academy a large collection of wood carving, stone carving, brick carving, pottery, plaster and iron engraving.

Fig. 6 Scheme of termite monitoring devices settled in the Chen Clan Academy

We applied 160 automatic termite monitoring systems at The Chen Clan Academy. All deployed devices were checked manually about the termite activity inside. According to data collected in 2022, among all 160 deployed devices, three of them sent false alarming messages (FP) (Table 4). Meanwhile, four devices were destroyed but no alarming messages received (FN). Collectively, we got accuracy rate of 95.4% of all automatic termite monitoring systems supplied at The Chen Clan Academy.

Conclusion

According to results from these representative sites, we conclude that our automatic termite monitoring system showed a high accuracy rate in detecting termite activity. This system is also durable for the multi-annual management of termite colonies in the complex outdoor environment and low cost to monitor the termite infestation.

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Friday | March 3, 2023 | 09:15-09:30

O_12

A novel wood preservative with vegetal extracts-cypermethrin combination for envelope treatment of wood against subterranean termites under H2-hazard class situations

by

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Abstract

In accordance with the requirements for the wood protection industries to develop cost-effective, environmentally acceptable wood treatment solutions replacing traditional biocides, this paper reports an aboveground subterranean test results of termite-susceptible heartwood of the tropical hardwood kempas (*Koompassia malaccensis*) envelope-treated with a novel wood preservative based on vegetal extracts-cypermethrin combination (Biocide 1: 0.16% cypermethrin, 0.08% tebuconazole, 2% vegetal extracts). Commercial permethrin-based LOSP (Biocide 2: 0.2% permethrin, 0.08% tributyltin naphthenate 1.8%, dichlorofluanid 0.1%) dip treatment served as the reference. Such conditioned treated kempas blocks were subjected to a rigorous laboratory volatilization regime (representing long-term evaporative ageing of treated wood used aboveground indoors as H2-hazard class situation) and then exposed for 6 months in the field but inside an aboveground containerized termite test design (Wong 2005 - representing severe H2-hazard class situation not subjected to wetting, soil and weather) at a humid forest site targeting *Coptotermes curvignathus* subterranean termites. Results demonstrated irrefutably that untreated kempas heartwood was severely attacked by *C. curvignathus* (mean mass loss: 70.4% and 20,416 mg) with low mean visual termite rating (2.4), unlike the kempas well protected with very low surface retention of Biocide 1 (mean mass loss: 0.66% and 207 mg) and very low surface retention of referenced Biocide 2 (mean mass loss: 1.01% and 306 mg), with both treatments similarly yielding the highest mean visual termite rating for all replicate kempas specimens (rating 10). Performance of both biocides were regarded the same but which differed significantly ($P<0.05$) from those untreated counterparts. Biocide 1 therefore has considerable anti-termite potential on wood exposed at least to long-term H2-hazard class situations.

Key words: wood protection, envelope treatment, pyrethroid, termite test, *Coptotermes curvignathus*, kempas

Introduction

Stringent environmental controls that are required of the wood protection industry in many progressive economies of the world, has led to the development of more environmentally acceptable wood treatment/protection strategies in which only sufficient amounts of preservative liquids in the formulation, accommodating a fit-for-purpose treatment rationale, are preferably applied to treat wood without consequent chemical wastage otherwise caused by excess treating solutions, therefore securing a low environmental impact at the workplace and benefits users of such treated wood products. Traditionally wood preservation using hazardous heavy metals, creosote and other organo-metals either as various forms of water-based solutions, in heavy oils or organic solvents that often require high preservative retentions in pressure-treated wood, have been developed that has invited serious concerns to workplace and environmental safety of such treated wood. Envelope wood treatment technology (used as dipping, spray-on or brush-on) with novel formulations has thus emerged, and partly focused on wood protection against termites and decay fungi of solid wood or wood composite. Presumably these formulations would be superior to traditional emulsifiable concentrates, suspension concentrates or light organic solvent formulations often using pyrethroid and other organic termiticides at high dosages (Sornnuwat et al. 1994, Peters and Creffield 2003, Donath et al. 2008, Sukartana et al. 2009, Tawi and Wong 2016). Termite testings of these traditional termiticides were also evaluated as pressure-treated wood when increased termiticide penetration into the wood was desired (Creffield et al. 2013, Scown and Creffield 2009).

A new generation of bio-based microemulsion termiticidal (pyrethroid-based) formulation technology with KO@LIB antioxidant additive (Messaoudi et al. 2018) has now emerged from the laboratory of Groupe Berkem (France), popular in Europe for envelope (dip)- and pressure-treatment of wood and wood-based products, and have been recently considered in Indonesia using the lowest emission costs (eco-costs) Life Cycle Assessment (LCA) methodology (Siswanti Zuraida et al. 2016). Also such enveloped-treated wood even conferred up to 8 mm cypermethrin penetration into the wood (Ruel et al. 2015). With expertise and knowledge in biocidal formulations, especially for wood preservation for over 50 years, Groupe Berkem patented the first microemulsion technology for dipping treatments in Europe. Such water-borne products can, with practical dipping or aspersion treatments and adequate dipping times and effective concentrations, also enhance durability performance of tropical hardwoods against termites under Malaysian H2-H3 biological hazard class conditions (Wong 2004) found in the humid and sub-tropics as was favourably reported in kempas dip-treated in a cypermethrin- and a permethrin-based patented microemulsion formulation (Messaoudi et al. 2020a,b). Yet another patented formulation of Groupe Berkem, based in part on cypermethrin-vegetal extracts combination (Synerkem technology) is developed as brushed-on envelope treatment to be considered for permanent wood protection in aboveground (H2 and H3 hazard class) situations. This paper presents key findings from the tropical (Malaysian) H2-hazard class subterranean termite test of the performance of this novel bio-based formulation on envelope-treated H2-weathered Malaysian hardwood kempas (*Koompassia malaccensis*) against subterranean termites *Coptotermes curvignathus*.

Materials and methods

The field trials were undertaken using an established H2-hazard class aboveground termite field test protocol (Wong 2005), meant to accelerate termite infestation (and exclude fungal mold growth and decay) and shielded from light and wetting, by exposure of test wood specimens aboveground contact inside covered containers filled with termite-susceptible wooden baits. Containers were sited on a peripheral humid peat swamp forest area in Kota Samarahan where subterranean termites *Coptotermes curvignathus* are prevalent. *Coptotermes curvignathus* is representative of the aggressive subterranean termites found attacking construction wood in Malaysia and much of Southeast Asia.

Table 1. Partial composition of candidate Biocide 1 and reference Biocide 2

Wood preservative	Nominal composition (%w/w)	Solvent	Application
Biocide 1 (Candidate)	Cypermethrin (CMT): 0.16% Tebucinazole (0.08%) Vegetal extracts (2%)	Water	Brush-on
Biocide 2 (Reference)	Permethrin (PMT): 0.2% Tributyltin naphthenate (1.8%) Dichlorofluanid (0.1%)	White spirit	Dipping

The Malaysian hardwood selected for the envelope preservative treatment and termite testing was the structural commercial termite-susceptible kempas (*Koompassia malaccensis*) heartwood, widely used in Malaysia and Indonesia. Replicated (n=8) air dried test blocks [2 x 2 x 5 (long.) cm] of kempas were dipped for 3 minutes, into nominal 0.2% permethrin-based LOSP (Biocide 2) and the solvent uptakes on freshly treated wood readily measured in order to estimate surface retention of permethrin. Another set of blocks were brushed-on with Biocide 1 until the wood surfaces were coated, and then immediately weighed in order to estimate surface cypermethrin retention. Description of Biocide 1 and Biocide 2 are given in **Table 1.** Freshly-treated blocks were then air dried for at least 8 weeks at room temperature tp permit adsorption of pyrethroid on the wood. To simulate long-term weathered condition of treated wood used aboveground indoors deemed as H2-hazard class situation (Wong 2004), treated and untreated blocks were next subjected to laboratory evaporative ageing (=volatilization) by oven drying at 40^{o}C for 18 days before termite testing. These untreated and treated H2-weathered wood blocks were exposed to subterranean termites *Coptotermes curvignathus* in the H2 hazard class field test of (Wong 2005) for 6 months. After six-month field exposure to termites, the H2-weathered test blocks were retrieved from the test assembly, cleaned and were visually rated for degree of termite attack on a 10-point AWPA E7-07 scale: 10 (sound), …, 6 (severe attack), …until 0 (Failure), and oven dried (105^{o}C) percent mass loss, absolute mass loss (milligram) of wood blocks determined (AWPA 2008).

Data were interrogated by One-ANOVA using MINITAB-14 software, with multiple comparison t-tests of mean values (for termite rating, percent mass loss, milligram mass loss) by Least Significant Difference (LSD, $P<0.05$) in order to examine the relative hardwood protection from termites accorded between Biocide 1, Biocide 2 and untreated H2-weathered woods blocks. Wood blocks envelope-treated with Biocide 1 and Biocide 2

Results and discussion

Synthetic pyrethroids in both biocide formulations are of interest here concerning kempas heartwood protection against *Coptotermes curvignathus* as fungicides of these biocides are regarded as not effective against termites. The 3-minute dipping of air dry kempas heartwood with reference Biocide 2 and the brush-on treatment of kempas with Biocide 1 yielded low mean retentions of each pyrethroid adsorbed on to the wood surfaces (calculated as either g/m^2, g/m^3 or %w/w) shown in **Table 2**. Notably, the low applied pyrethroid concentrations in these biocides (0.16% cypermethrin, 0.2% permethrin) were considerably less or quite similar to that normally applied by others (eg. Read and Berry 1984, Sornnuwat et al. 1994, Tawi and Wong unpublished data 2019) which expectedly yielded considerably low surface retention expressions shown (**Table 2**). Mean Biocide 1 cypermethrin retention in (0.004 %w/w, 24.76 g/m^3) differed from that found for kempas dip-treated with 0.16% cypermethrin in microemulsion solution (0.0047 %w/w, 40.54 g/m^3) of Messaoudi et al. (2020b). Mean Biocide 2 permethrin retention in kempas (0.0042 %w/w, 25 g/m^3) also differed from that in kempas dip-treated with 0.2% permethrin in microemulsion solution (0.0039 %w/w, 36.21 g/m^3) of Messaoudi et al. (2020b). It is probable that microemulsion solutions of Messaoudi et al. (2020a, b) can yield slightly higher retention of these pyrethroids than either Biocide 1 or the reference Biocide 2. Notably, despite the low kempas surface retention of these pyrethroids from Biocide 1 and Biocide 2, both treated H2-weathered treated kempas was nevertheless immune to termite attack compared to untreated H2-weathered kempas, based on mean wood percent mass loss, mean milligram wood mass loss and mean visual termite rating values (**Table 3**). There were highly significant differences ($P<0.05$) in mean termite attacks between treated and untreated kempas [mean termite rating 10 for both biocides versus 2.4 (untreated); mean mass loss 0.66 %w/w (Biocide 1) or 1.01 %w/w (Biocide 2) versus 70.4 %w/w (untreated); mean absolute mass loss 207 mg (Biocide 1) or 306 mg (Biocide 2) versus 20,416 mg (untreated)] while comparable excellent performance by Biocide 1 and Biocide 2 was confirmed.

For comparison with previous applications of pyrethroids in traditional formulations, Read and Berry (1984) revealed that a 0.1% concentration of cypermethrin emulsion using surface application was sufficient against *Reticulitermes* termites. Zaidon et al. (2008) found that exposure of rubberwood particleboard, empty fruit bunch (EFB) particleboard and Rubberwood-EFB particleboard sprayed with 0.2% permethrin solution yielded low mean mass loss (range: 7.2 – 12.1%) though failed to confer complete protection, unlike their untreated susceptible counterparts (range: 17.8 – 31.1%) against *Coptotermes curvignathus*. Excellent protection was reported from a laboratory evaluation of 5-min dip-treated rubberwood blocks exposed to *Coptotermes gestroi* at 0.015, 0.25 and 0.5% cypermethrin and at 0.5, 1 and 2% permethrin (Sornnuwat et al. 1994). Recognizing that such laboratory screening tests are not necessarily comparable with field termite tests which are realistic to wood protection applications, H2-hazard class termite tests (Tawi and Wong unpublished data 2019) revealed instead a relatively higher levels of both emulsifiable concentrate-based permethrin (1.69 - 6.75%) and cypermethrin (1.68 - 3.35%) agropesticides needed to fully protect hardwoods from *C. curvignathus* attack. Messaoudi et al. (2020b) reported that a 3 minutes dipping time protected weathered treated kempas remarkably well against termites under H2 and H3 hazard classes even at their lowest pyrethroid concentrations of microemulsion formulation solution. Also the applied pyrethroid concentrations used with Biocide 1 and microemulsion solutions of Messaoudi et al. (2020a, b) were comparably effective to those generally confirmed efficient against *Reticulitermes* termites (Adkalis 2018a, b).

Table 2. Nominal surface retention of synthetic pyrethroid in wood determined by solution uptake of Biocide 1 (brush-on) and Biocide 2 (dipping)

Wood preservative	Nominal composition of pyrethroid (%w/w)	Mean retention (%w/w)	Mean retention (g/m^2)	Mean retention (g/m^3)
Biocide 1 (Candidate)	Cypermethrin: 0.16%	0.0040 (0.0002)	0.14 (0.006)	24.76 (1.05)
Biocide 2 (Reference)	Permethrin: 0.2%	0.0042 (0.0004)	0.14 (0.008)	25.00 (1.51)

n=8; ( ) = standard error of the mean

Table 3. Mean values of termite attack parameters comparing 2 treated and 1 untreated kempas heartwoods

Treatment	Percent mass loss	Absolute mass loss (mg)	Termite rating
Untreated, H2-weathered	70.4 (14.2)	20,416 (4110)	2.4 (1.2)
Biocide 1 Surface-treated with cypermethrin/vegetal extracts combination, H2-weathered	0.66 *a* (0.04)	207 *a* (10)	10 *a* (0)
Biocide 2 Surface-treated with LOSP containing permethrin, H2-weathered	1.01 *a* (0.41)	306 *a* (125)	10 *a* (0)
LSD values	24.21	6984	2.1

LSD values used for comparison within-column mean values: within-column means sharing same letter denotes that mean values do not differ at $P<0.05$ sig. level; n=8; ( ) denotes standard error of the mean.

By contrast, under similar conditions, traditional pyrethroid formulations (eg. emulsifiable or suspension concentrates) could confer termite resistance of dip-treated wood either at longer dipping (steeping) durations, and/or increasing pyrethroid concentrations with consequent termiticide retentions in wood (Sornnuwat et al. 1994, Kamdem et al. 1996, Ma et al. 2013, Tawi and Wong unpublished). Since preservative performance against wood-degrading organisms obviously depends mainly on wood species, target preservative retention, treating concentrations and treatment methods, and penetration of the preservative into the wood, the unique envelope treatment microemulsion technology reported by Messaoudi et al. (2020a, b) can provide up to 8 mm pyrethroid penetration into wood (Ruel et al. 2015) for termite durability performance in aboveground contact when adequate wood treatment parameters are applied. There may well be also good pyrethroid penetration into kempas shown by the excellent termite resistance performance of Biocide 1 (present study) based on the Synerkem technology of Groupe Berkem (France) where the component vegetal extracts are claimed to act as a booster in wood protection, and cypermethrin in Biocide 1 is readily diffused into wood cell walls and rendered still fixed to the wood after evaporative ageing treatment (Ruel et al. 2015).

Elsewhere, the Australian Standard (2005) for preservative treatment of sawn and round timber specifies a relatively higher minimum retention of cypermethrin (0.03%w/w) and permethrin (0.02%w/w) within the 5 - 8 mm penetration zone especially for microemulsion or LOSP-based double-vacuum treated wood for H2-and H3-hazard class uses. Hence the present termite test on Biocide 1, as with that of Messaoudi et al. (2020a, b), using considerably lower cypermethrin surface retention (comparable to the reference Biocide 2) yet able to protect kempas against termites.

Conclusions

The patented Biocide 1 formulation (comprising cypermethrin, tebuconazole, vegetal extracts) provided excellent protection of H2-weathered treated kempas from subterranean termites aboveground contact indoors exposure, comparable to the reference LOSP Biocide 2 (comprising permethrin, tributyltin naphthenate, dichlorofluanid), while preliminary observations (to be reaffirmed) even suggest that Biocide 1 could be used to protect wood under H3-weathered situations (treated wood exposed aboveground, outdoors). Thus Biocide 1 is a promising eco-friendly and cost-effective new generation wood preservative for aboveground wood protection.

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Poster Presentation

Thursday | March 2, 2023 | 14:30-15:00

P_01

Biodiversity of termites in protected area at Chiang Mai University Hariphunchai Centre, Lamphun Province

by

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Abstract

Termites are major decomposers in tropical and subtropical forests, and different genera contribute to different humification process. Understanding termite diversity is the key to understanding the diversity and stability of humification process in a forest. In this study, we investigated termite diversity and analyzed soil pH value in three locations in Protected Area at Chiang Mai University Hariphunchai Centre (Lamphun Province, Thailand) monthly, from June 2021 to January 2022. The three study sites included a bamboo forest, a deciduous dipterocarp forest and a mixed deciduous forest. A total of 186 specimens were collected and eight termite genera were identified, including the wood-feeders *Globitermes* and *Microcerotermes*, the litter-feeders *Hypotermes*, *Macrotermes*, and *Odontotermes*, the soil-feeders, *Termes* and *Dicuspiditermes*, and the lichen-feeder *Hospitalitermes*. Highest species diversity was observed in deciduous dipterocarp forest (Shannon's diversity index: H' = 1.61), followed by bamboo (H' = 1.58) and mixed dipterocarp forest (H' = 1.56). High species evenness was observed in bamboo forests (Shannon evenness index: SEI = 0.61), followed by mixed deciduous forest (SEI = 0.55) and deciduous dipterocarp forest (SEI = 0.53). The termite density was not correlated with soil pH ($P<0.05$) in three forest areas. The number of termite genus was high in rainy season and low in dry season, and was positively correlated with rainfall and temperatures. We propose that deciduous dipterocarp forest provide abundant dead branches and leaf-litters for *Microcerotermes* and litter-feeders and led to high species diversity.

Key words: termite diversity, carbon-cycling, seasonal termite occurrence, humus decomposer, tropical forest ecosystem

Thursday | March 2, 2023 | 14:30-15:00

P_02

Spatial understanding mediated by thigmotaxis in the soldier of subterranean termite *Coptotermes formosanus*

by

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Abstract

Thigmotaxis, or the preference of being in close range to the wall or the surrounding perimeter, is preferred by insects such as termites that like to search for crevices or live in a closed environment. However, the information on thigmotaxis has not been well studied in termite that depend on the gallery systems, especially subterranean termites. In this study, the movements of soldier termite in closed and open chambers were observed. Two groups of soldier termites were prepared: a normal antennae group and cut antennae group. Trajectory of soldier termite was recorded in 10 minutes and observed by an image-based quantitative analysis. Soldier termites with normal antennae in the closed chamber had circular orientation along the chamber wall. In the open chamber, trajectory concentrated near the opening by having significantly higher presence rate compared to the one in the closed chamber. Loss of the antennae disturbed the preference to be in close range with the chamber wall or the opening and forced the termite soldier to frequently detach from the chamber wall. Thigmotaxis was illustrated to be important for subterranean termite spatial understanding, mediated by the antennae as their tactile organs.

Key words: *wall following behavior, defensive caste, tactile sensory, flagellomere, setae*

Thursday | March 2, 2023 | 14:30-15:00

P_03

Efficacy and versatility of a plant bio-based anti-termite product

by

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Abstract

Wood as a material presents many advantages, from aesthetic to technical points of view. Timber stores carbon and this is a major pathway for climate change mitigation. However, this eco-material is also prone to degradation which counteracts long-term carbon storage. In most cases (i.e. when its natural durability is not sufficient), wood must be treated preventively against wood destroying organisms such as termites. In order to comply with the existing biocide regulations, a plant bio-based product, using anti-oxidant and biological properties of polyphenols, has been developed. This product has been tested for its efficacy by: (i) rapid laboratory screening tests on cellulose paper against *Reticulitermes flavipes,* (ii) laboratory tests according to the guidelines of EN117 tests against *Coptotermes gestroi* and *Prorhinotermes canalifrons* and (iii) soil treatment tests against *C. gestroi.* This work reports the product performances conducted for the different test methods and termite species, which helps to explain the mode of action of the plant-based active ingredients (polyphenol) in the product formulation.

Key words: *Reticulitermes*, *Coptotermes*, *Prorhinotermes*, polyphenol, wood protection system

Thursday | March 2, 2023 | 14:30-15:00

P_04

Termite survey on cultural heritage buildings: Case study in Central Java, Indonesia

by

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Abstract

Central Java province is located in the middle of Java Island, Indonesia with a vibrant, rich, and diverse cultural legacy such as dance, traditional music, and architecture. Central Java has many important heritage buildings that are significant to the region's history and culture, for example: Borobudur Temple, Prambanan Temple, Taman Sari Water Castle, etc.. Most of the historical buildings are made of wood, which puts them at risk from wood-destroying organisms like termites and beetles as well as fungi that cause wood decay. Since these damaging insects and microorganisms are present, the protection of many of these historic structures is currently insufficient. Therefore, this research was conducted to collect data on termite species that attack historical buildings in Central Java. The information from this research could be used as a reference for applying termite control methods. The survey was conducted in 15 registered historical buildings in the Central Java region, namely: Kemandungan ward, Gede Kauman Mosque, Blandar Keraton, Soko Keraton, Kagungan dalem rotowijayan grand mosque, dalem patehan lor, joglo jagalan traditional house, Kota Gede Mosque, Agung Plerest Mosque, Sultan Agung Imogiri graveyard, and Raden Pekik Banyusun. A termite infestation was surveyed from the main building, the area surrounding the building, and the furniture. The result showed that the termite species were *Macrotermes* sp., *Cryptotermes* sp., *Coptotermes* sp., *Nasutitermes* sp., and *Odontotermes* sp.

Key words: termite survey, distribution, heritage buildings

Thursday | March 2, 2023 | 14:30-15:00

P_05

The prospect of potential compounds from termite-fungi interaction for aggregation behavior of subterranean termite

by

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Abstract

Termites and fungi, such as Basidiomycetes, somehow exhibit positive interaction. The interaction of fungi and insects is assumed to have an important function, such as utilizing fungi as a food source for insects, competing over the same resources by insects and fungi, or regulating insect behavior by fungi. A study reported that brown rot fungus-infected blocks were highly selected by *Reticulitermes flavipes*. The basal portion of the blocks infected with *Lenzites trabea* was much more attractive than that of the other blocks. The fungus or fungal product might affect termites' ability to locate decaying wood. In our previous study, we found some potential compounds detected in several fungal extracts that induce preference behavior in termites, such as hexadecane, dodecane, tetradecane, and methyl 2-furoate. In this study, we conducted a further analysis using synthetic compounds of those potential compounds through bioassays of the synthetic compounds against subterranean termites (*Coptotermes sp.).* The termites were exposed to the suspected potential compound for 24 hours. The observation was illustrated as an aggregation index (AI) value. The AI value indicates that two compounds, hexadecane and methyl 2-furoate, induce aggregation behavior in termites with a positive aggregation index value. The main compound of wood, hexadecane, had the highest AI in the first hour, then decreased after 3 hours of observation. In contrast to methyl 2-furoate, a specific compound of wood decayed by the M7 fungal code that increased AI at 3 hours, then decreased and remained constant until 24 hours. Then, we suggest that termite aggregation behavior is poorly induced by a single volatile compound but that a synergism effect of volatile compounds derived from wood or fungi may accelerate termite aggregation. Then, we suggest that aggregation behavior of termites is poorly induced by a single volatile compound, but a synergism effect of volatile compound of either originated from wood or that of fungi may accelerate aggregation response of termite.

Key words: brown rot fungi, subterranean termite, aggregation, synthetic compound, synergism

Thursday | March 2, 2023 | 14:30-15:00

P_06

Fecal pellet dimension as a potential non-destructive species marker for cryptic drywood termite species

by

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Abstract

Drywood termite is well-known for its cryptic life since it dwells inside dry wood for almost the entirety of its lifecycle. Its cryptic life also contributed to its considerable potential to be spread out unchecked to new areas, especially in the current globalized trade. Furthermore, its silent infestation on wood-based material has caused substantial economic damage. Hence, concern over additional economic damage by the new spread of drywood termites to new areas is possible which necessitates the presence of a reliable non-destructive species marker. To address this challenge, we measured the length, width, perimeter, and top view surface area of fecal pellets of two invasive drywood termites (*Cryptotermes dudleyi* and *Incisitermes minor*) that infested structural woods collected from Indonesia and Japan. We also assembled two dimension index of "shape ratio" and "enclosure ratio" of measured fecal pellets. Our results following quadratic discriminant analysis on these fecal pellet dimensions showed that it was possible to pick the right species at 70 to 77% at a time. However, our result also showed that wood species do affect fecal pellet shape (dimension index) within species (t-test; $P<0.0001$). Hence, future study is needed to test the stability of the dimension index once both drywood termite species fed on the same wood species.

Key words: drywood termite, non-destructive species marker, fecal pellets

Thursday | March 2, 2023 | 14:30-15:00

P_07

Envelope wood protection against subterranean termites under H2-hazard class situations by a new generation wood preservative with vegetal extracts-cypermethrin components

by

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Abstract

Wood protection industries in progressive economies globally are responsible for developing cost-effective, environmentally acceptable wood treatment solutions for long term carbon storage in wood materials/products while appealing to consumer needs for such treated products with low environmental impact. A new generation wood preservative, based in part on vegetal extracts-0.16% cypermethrin components, has considerable potential in conferring long term wood protection against subterranean termites when exposed to indoor aboveground contact. Applying only surface (envelope) treatment of kempas (*Koompassia malaccensis*) hardwood with this preservative and subsequently subjecting treated wood to a rigorous laboratory evaporative ageing protocol (regarded as H2-weathered treated wood), an H2-hazard class aboveground subterranean termite test design (Wong 2005) was used to determine the termite resistance of such treated wood. Reference surface-treatment preservative was a commercial LOSP containing partly 0.2% permethrin. After 6 months exposure of treated wood at a forest site against *Coptotermes curvignathus*. Results demonstrated irrefutably that unprotected kempas heartwood was severely attacked by *C. curvignathus* (mean mass loss: 70.4% and 20,416 mg) with low mean visual termite rating (2.4), unlike the kempas TOTALLY protected by both the new generation preservative and the reference LOSP preservative despite very low surface pyrothroid retention detected from these treatments. This cypermethrin-based formulation therefore has considerable long-term anti-termite potential on wood exposed aboveground indoors.

Key words: wood protection, envelope treatment, pyrethroid, termite test, *Coptotermes curvignathus*, kempas

Thursday | March 2, 2023 | 14:30-15:00

P_08

A new generation bait matrix with vegetal extracts-diflubenzuron components, for the control of Asian subterranean termites *Coptotermes gestroi* (Blattodae: Rhinotermitidae) in Reunion Island

by

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Abstract

The efficacy of anti-termite bait pebble dosed at 0.3% w/w of Diflubenzuron, and Chitin Synthesis Inhibitor (CSI) and 0.6% w/w of a biobased booster (natural plant), was evaluated in the laboratory on the Asian subterranean termite *Coptotermes gestroi (*Wasmann). Four concentrations 33.3%, 50%, 50% bis and 100% as well as two neutral matrices, were used in two in-house developed test methodologies. In the arenas of choice, after 5 days of installation, the rate of individuals presents in concentrations 33.3% and 50% was significantly higher than in other concentrations. Total mortality of individuals was observed within an average of 70 days in the two arenas of choice. In the no-choice trials, mortality was significantly higher at 36 days of exposure for concentration 33.3% and 43 days for concentration 50%. The combination of these two test modalities suggests good results for the control of populations of *Coptotermes gestroi* subterranean termites exposed to these two concentrations of this new generation bait matrix with Vegetal Extracts-Diflubenzuron components. The neutral matrix based on pure cellulose and plant extract, to demonstrate good nutritional value for termites compared to the commercial neutral matrix.

Key words: termites, *Coptotermes gestroi,* plant extract, molting inhibitor, arena of choice, anti-termite baits, overseas department

P_09

Efficacy performance of bio-based termiticide containing plant polyphenolic extracts from Berkem Biosolutions® against subterranean termites *Coptotermes gestroi* in soil treatment test

by

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Abstract

The efficacy performance of a bio-based termiticide product containing plant polyphenolic extracts from Berkem Biosolutions® was evaluated in a soil treatment test against subterranean termites, *Coptotermes gestroi*. The laboratory assessment was carried out using a Bottle H test unit (Fig. 1) following the Japan Wood Preservation Association (JWPA) standard, JWPAS-TS-(1) 2018. The soil (20 mesh) was treated with the bio-based termiticide product with a concentration of 5 L/m² and air-dried for 1 week. The treated soil (7 g) was put into a glass tube tunnel (5 cm in length; 1.5 cm in diameter), while the untreated soil was added at the edge of the glass tube (Fig. 1). For the control unit, untreated soil was put into the 5 ml glass tube tunnel as well as the glass container. A set number of *C. gestroi* (150 workers and 15 soldiers) were introduced into one side of a glass container (12 cm in height; 5 cm in diameter), while a rubberwood with the dimension of 20 (R) x 20 (T) x 10 (L) was placed in the opposite side to lure termite (Fig 1). The length of tunnel penetration (mm) of treated and untreated soil (control unit) by termites was observed every day for 21 days to determine the efficacy score and criteria (Table 1). Termite mortality rate was recorded at the end of the test period. The test is deemed valid if the mortality rate in the control units does not exceed 20%. The results suggested that the product showed high resistance (efficacy score = 1) against *C. gestroi*. There was no termite penetration in all treated-soil test units, indicating that the product provided good soil-barrier protection. The product also showed a high lethal effect on *C. gestroi*, as indicated by a 100% termite mortality rate in all treated-soil test units.

Key words: soil treatment, bio-based termiticide, plant polyphenolic extract, *Coptotermes gestroi*

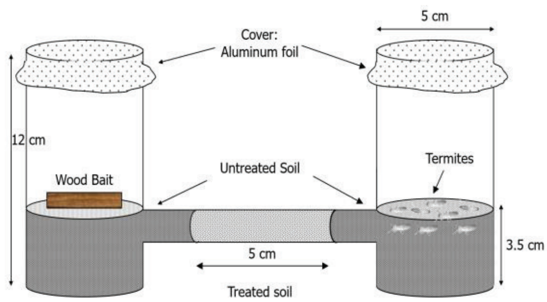

Fig 1. The Bottle H test unit

Table 1. The efficacy criteria of soil treatment test, based on the length of penetration by termites in the glass tube tunnel.

Length of tunnel penetration (cm)	Score	Efficacy Criteria
0 – 1.0	1	High resistance
1.1 – 2.0	2	Moderate resistance
2.1 – 3.0	3	Low resistance
> 3.0	4	Non- resistance