

2026.03.12-13 **PRTRG 16** Hanoi  
Pacific Rim Termite Research Group Conference  
La Thanh Hotel - 226 Van Phuc, Ngoc Ha, Hanoi

# Program Book and Proceedings





PACIFIC RIM  
TERMITE  
RESEARCH GROUP

# **The 16<sup>th</sup> Pacific Rim Termite Research Group (PRTRG) Conference**

**La Thanh Hotel – 226 Van Phuc, Ngoc Ha, Hanoi  
Vietnam  
March 12 – 13, 2026**

# **Program Book and Proceedings**

## Organized By:



The Institute of Ecology and Works Protection (WIP)



## Supported By



ZM Crop Protection Corporation



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## Foreword of the President



On behalf of the Pacific Rim Termite Research Group (PRTRG), I am delighted to welcome you to the 16th PRTRG Conference in Hanoi, Vietnam. It has been fourteen years since our last meeting in Vietnam, and we sincerely thank the Institute of Ecology and Works Protection (WIP) for hosting this conference once again.

This meeting features six distinguished keynote and plenary speakers, along with 25 oral and 10 poster presentations covering diverse topics in termite biology and pest management. These contributions reflect the conference theme, Termites in a Changing World: Climate Change, Pest Invasion, and Strategic Control Solutions. We are pleased to welcome nearly 150 participants from 17 countries.

I would also like to express our appreciation to our sponsors—Bentz Jaz, Groupe Berkem, and ZM Crop Protection Corporation—for their generous support.

I hope you enjoy the scientific exchange, as well as the culture and cuisine of Vietnam, and that you have a memorable and rewarding time in Hanoi.

Sincerely,

Hou-Feng Li  
President, Pacific Rim Termite Research Group



PACIFIC RIM  
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## HANOI, VIETNAM

Welcome to Vietnam! A vibrant Southeast Asian nation known for its rich history, diverse cultures, and dynamic growth. From the ancient traditions of the Red River Delta to its rapidly developing urban centres, Vietnam offers a unique blend of heritage and innovation. Its warm hospitality, renowned cuisine, and strong academic and scientific communities make it an inspiring setting for international collaboration and knowledge exchange.

We are especially delighted to gather in Hanoi, the thousand-year-old capital city and cultural heart of the country. With its tree-lined boulevards, serene lakes, and historic landmarks such as the Old Quarter and Hoan Kiem Lake, Hanoi reflects a harmonious balance between tradition and modernity. As the venue of the 16th Pacific Rim Termite Research Group Conference, Hanoi provides an ideal backdrop for meaningful discussions, new partnerships, and advances in termite research across the region.

We warmly welcome all delegates and wish you a productive conference and a memorable stay in Vietnam.



# Program Agenda

Thursday | March 12, 2026

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07:30-08:40	Registration
08:40-09:00	Opening Ceremony Welcome Speech – President of PRTRG and Director of the Vietnam Academy for Water Resources (VAWR)

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**Keynote Lecture** Moderator: Hou-Feng Li

09:00-09:40 **K\_01 Evolution of Termite Genomes**  
Tom Bourguignon

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09:40-10:20 **K\_02 Biodiversity of Termites in Vietnam**  
Nguyễn Văn Quảng

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10:20-10:40 Photography Session – *Tea Break*

**Kunio Tsunoda Memorial Lecture** Moderator: Chow-Yang Lee

10:40-11:10 **M\_01 Understanding the prey composition and life history of Chinese pangolins to enhance ex situ conservation strategies**  
Ching-Min Sun

11:10-11:40 **M\_02 Friend or Foe: The Formosan Subterranean Termite**  
Sang-Bin Lee

11:40-12:10 **M\_03 From Solitary Insect to Social Colony: Genomic Remodeling of Sensory Receptors in Termite Sociality**  
Bosheng Chen

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**Dr Donald Ewart Memorial Lecture** Moderator: Chow-Yang Lee

12:10-12:30 **M\_04 Expansion of *Incisitermes minor* into Pacific Rim Countries**  
Partho Dhang

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12:30-13:30 *Lunch*

## Oral Presentation

**Session 1: Termite Biology: Biodiversity, Evolution, and Physiology** Moderator: S Khoirul Himmi

13:30-13:42 **O\_01 A new species of subterranean termite in the genus *Reticulitermes* from southern California**  
Chow-Yang Lee\*, Joanne Tzu-Chia Chen

13:42-13:54 **O\_02 Combining ecology, genomics and ontogeny to define sociality in termites**  
Cedric Aumont\*, Thomas Bourguignon, Dino McMahon

- 13:54-14:06 **O\_03 Unraveling termite evolution with high-resolution genome assemblies**  
 Cong Liu\*, Cedric Aumont, Alina A. Mikhailova, Tracy Audisio, Simon Hellemans, Yi-Ming Weng, Shulin He, Crystal Clitheroe, Zongqing Wang, Ives Haifig, David Sillam-Dusses, Ales Bucek, Gaku Tokuda, Jan Sobotnik, Mark C. Harrison, Dino P. McMahon, Thomas Bourguignon
- 14:06-14:18 **O\_04 The evolution of visual opsin genes in termites**  
 Yi-Ming Weng\*, Thomas Bourguignon
- 14:18-14:30 **O\_05 Exploring the Mechanism by Which Ionotropic Receptor IRx Regulates Humidity Sensing Behavior in *Coptotermes formosanus***  
 Chenxin Wu\*, Weisong Zhao, Dayu Zhang, Bosheng Chen
- 14:30-14:42 **O\_06 Functional Analysis of Antifreeze Proteins (AFPs) in the Cold Tolerance of *Reticulitermes flaviceps***  
 Yanmin Ma\*, Baoling Li, Bosheng Chen, Dayu Zhang
- 14:42-15:00 **Q&A Session**

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15:00-15:30 Poster Presentation – *Tea Break*

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### Oral Presentation

#### Session 2: Termite Biology: Behavior Ecology

Moderator: Chun-I Chiu

- 15:30-15:42 **O\_07 Elevational intraspecific body size patterns in termites depend on feeding habits.**  
 Chia-Chien Wu\*, Wen-Jun Lin, Hsin-Ting Yeh, Hou-Feng Li
- 15:42-15:54 **O\_08 Machine Learning-Based Assessment of Termite Distribution and Climate-Driven Range Shifts in China**  
 Ziyi Feng\*, Yanmin Ma1, Bosheng Chen, Dayu Zhang
- 15:54-16:06 **O\_09 Polyethism in process of food processing within *Odontotermes hainanensis* (Isoptera: Macrotermitinae)**  
 Nguyen Thi My\*, Nguyen Quoc Huy, Nguyen Minh Duc, Nguyen Thuy Hien, Dang Ngoc Bich, Nguyen Van Quang
- 16:06-16:18 **O\_10 Colony Development Under Stress: Impacts of Forager Loss on Reproductive Performances in Early-Stage Termite Colonies**  
 Hendra Kurniawan Maury\* (Travel Fund recipient), Intan Ahmad, Rudi Dungani, Ramadhani Eka Putra, Hou-Feng Li
- 16:18-16:30 **O\_11 Functional Adaptations of Shelter Tubes in Higher Termites (Blattodea: Termitidae)**  
 Sinsap Wongkoon\* \*(Travel Fund recipient), Chun-I Chiu, Piyawan Suttiprapan
- 16:30-16:42 **O\_12 Plastic development pathway of reproductive caste of *Prorethinosia flavus* (Blattodea: Psammotermitidae)**  
 Wan-Jen Li\*, Yi-Ning Chiu, and Hou-Feng Li

16:42-17:00 **Q&A Session**

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17:00-17:15 Closing of Day 1

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17:15-18:15 Biennial General Meeting (Member Only)

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19:00-21:00 *Welcome Dinner*

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# Program Agenda

Friday | March 13, 2026

## Oral Presentation

### Session 3: Termite Management: Chemicals

Moderator: Ikhsan Guswenrivo

- 08:00-08:12 **O\_13 KMITL Nano-Oil: Essential Oil Nanoemulsion for Termite Control**  
Chaiamon Chantarapitak\*, Jarongsak Pumnuan, Chaiwat Chanpitak and Somsak Kramchote
- 08:12-08:24 **O\_14 Fluorescence of Metamisalt as a termiticide**  
Makoto Horinouchi\*, Takeshi Yamaga
- 08:24-08:36 **O\_15 Sustainable biobased polyamide for termite proof jacketing solutions**  
Atsushi Yoshitake
- 08:36-08:48 **O\_16 Efficacy of Arnica Extract-Based Termiticide from Berkem Biosolutions® in Subterranean Termite Control: A Comprehensive Laboratory and Five-Year Field Evaluation**  
Daouia Messaoudi, S Khoirul Himmi\*, Didi Tarmadi, Ikhsan Guswenrivo, and Sulaeman Yusuf
- 08:48-09:00 **O\_17 2-Phenoxyethanol Directs Subterranean Termite Soil Foraging**  
Enrico Levi\*, Allen Fugler, and Phil Koehler
- 09:00-09:15 **Q&A Session**

## Oral Presentation

### Session 4: Termite Management: Strategy and Policy

Moderator: To Thi Mai Duyen

- 09:15-09:27 **O\_18 Characteristics of termite damage to historical monuments in Ha Nam (currently part of Ninh Binh Province) and proposed control solutions**  
Nguyen Thi My, Nguyen Quoc Huy, Nguyen Minh Duc, Nguyen Thuy Hien, Ha Tra My\*, Dang Ngoc Bich, Vo Thi Thu Hien, Nguyen Thi Hong Nhung
- 09:27-9:39 **O\_19 Termite damage and management in Korean wooden architectural heritage: a 20-year review and future perspectives**  
Sihyun Kim\*
- 09:39-09:51 **O\_20 Area-Wide Evaluation of Bait Density and Cost-Effectiveness in the Elimination of the Formosan Subterranean Termite (Blattodea: Heterotermitidae)**  
Wen-Jun Lin\*, Guan-Yu Chen, Ning Chen, Yu-Yi Lai, Chien-Hung Huang, and Hou-Feng Li
- 09:51-10:03 **O\_21 Application of Termite Monitoring System Based on DEMINL Technology in Dam Termite Control**  
Shi Jin, Wu Ling-li\*, Chen Bo-sheng, Shen Jun-feng, Zhong Jun-hong
- 10:03-10:20 **Q&A Session**

10:20-10:40 Poster viewing – Tea Break

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**Oral Presentation****Session 5: Ecology of Termitophagus Mammals**

Moderator: Katrina Buenvenida

- 10:40-10:52 **O\_22 Foraging Ecology of Juvenile Chinese Pangolins (*Manis pentadactyla*)**  
Chung-Ching Liu\* (Travel fund recipient), Nick Ching-Min Sun
- 10:52-11:04 **O\_23 Effects of Agricultural Management Practices on Pangolin Habitats and the Composition of Ants and Termites in Mid-Elevation Orchards in Taiwan**  
Chih- Hsia Yang\*, Nick Ching-Min Sun, Ya-Hui Chuang
- 11:04-11:16 **O\_24 Effect of Termite and Ant Abundance on Chinese Pangolin (*Manis pentadactyla*) Activity**  
Jia-Tsai Yang\*, Hsiang-Ling Chen, Hou-Feng Li
- 11:16-11:28 **O\_25 Analysis of Seasonal Variations and Influencing Factors in the Fecal Inorganic Matters of the Chinese Pangolin**  
Szu-Cheng Chien\*, Nick Ching-Min Sun
- 11:28-11:45 **Q&A Session**

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11:45-12:00 The next PRTRG 16 Conference Announcement

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12:00-13:30 *Lunch* and Preparation for the Excursion

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13:30-18:00 Excursion Program

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18:30-21:00 *Gala Dinner and Closing Ceremony*

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# List of Poster Presentations

March 12 - 13, 2026

**P\_01 Preliminary effects of a natural bait on *Coptotermes gestroi***

Florent Chopinet\*, Stéphane Savriama, Selven Narraina Pillay and Daouia Messaoudi

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**P\_02 Shifts in soil microbial community composition correlated with termite presence in a historic Korean temple environment**

Young Hee Kim\*, Boa Lim, Jeung Min Lee, Jin Young Hong

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**P\_03 Morphological and Molecular Characterization of a Geographically Isolated *Hodotermopsis* Population from Shikoku, Japan**

Kumiko Kihara\*, Kouki Matsuoka, Akinori Yamada, Kei Matsushima, Kei Hashimoto, Kiminori Toyooka, Shigeharu Moriya, Yuichi Hongoh

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**P\_04 Development of a termite monitoring device based on DEMINL technology with high attractant performance to termites and automatic bait release system**

Baoling Li\*, Bosheng Chen, Junfeng Shen, Hai Xu<sup>2</sup>, Dayu Zhang

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**P\_05 Introduction of Intelligent Termite Monitoring Technology : AI Image Recognition Technology**

Jing Yao, Mingzhi Yu

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**P\_06 Termite Durability of Bifenthrin-treated plywoods of Mixed Tropical Hardwoods - Relevance to Southeast Asia**

Malcolm Farmer, Andrew H.H. Wong\*, Shawn Cheng

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**P\_07 Mangiferin and dampwood termites: contrasting behavioural responses in *Prorethra sp.***

Florent Chopinet\*, Stéphane Savriama, Selven Narraina Pillay, Gary Mares

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**P\_08 Local emergence of *Prorethra sp.* in southern Réunion Island: spatial patterns, built environments and implications for integrated management**

Florent Chopinet\*, Stéphane Savriama

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**P\_09 Connected stations: from bait to termite activity monitoring**

Mathias Boutin, Florent Chopinet, Stéphane Savriama and Daouia Messaoudi\*

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**P\_10 Field Performance of Arnica Extract-Based Termiticide from Berkem Biosolutions® - Polyphenolic Plant Extract against Philippine Subterranean Termites**

Daouia Messaoudi\*, Menandro Acda

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## KEYNOTE LECTURE

### Evolution of Termite Genomes



Thomas Bourguignon  
Okinawa Institute of Science and Technology Graduate University, Okinawa  
Japan

Termites form a clade of social cockroaches that became particularly abundant in tropical ecosystems, where they play a key role as decomposers of organic matter at various stages of decomposition, from wood to soil. The genomes of a few termite species have already been sequenced; however, the number of available genomes is insufficient to investigate the genetic mechanisms behind the ecological success of these insects. In this keynote presentation, I will present the results we obtained from the analysis of 47 newly sequenced blattodean genomes, including 45 genomes of taxonomically and ecologically diverse termite species and the genomes of two cockroach outgroups (*Cryptocercus meridianus* and *Blatta orientalis*). Our analyses revealed the similarity between the genomes of *Cryptocercus* and termites, which are smaller than the genomes of other cockroaches. Amongst termites, Termitidae have the largest genomes with a higher proportion of transposons and more genes than other termites, owing to gene number expansion early on in the evolution of Termitidae. Gene expansion also affected the CAZyme repertoire, the genes involved in lignocellulose degradation. Finally, I will present some analyses of the termite transposon landscapes and their role in termite evolution.

## KEYNOTE LECTURE

### Biodiversity of Termites in Vietnam



Nguyen Van Quang  
VNU University of Science  
Vietnam

Termites (Isoptera) are a group of social insects that originated in the late Jurassic period (Engel et al., 2009), approximately 30 million years earlier than ants, and are classified as the suborder Isoptera within the order Blattaria (Krishna et al., 2013). Termites exhibit a high level of species diversity, with a total of 3,219 known species (3000 living and 219 fossils) (Constantino, 2020). Vietnam is in the tropical climatic zone, where environmental conditions are highly favorable for termite development. Research on termites in Vietnam has been conducted since the early twentieth century. Bathellier (1927) carried out studies on termites in Indochina and recorded 19 species occurring in Vietnam. Harris (1968) subsequently reported 27 species. Nguyen Duc Kham et al. (2007) published a monograph on the termite fauna of Vietnam, documenting a total of 101 species. Trinh Van Hanh et al. (2010) further summarized and recorded 141 termite species in Vietnam. More recently, Nguyen Quoc Huy et al. (2021) reported 251 termite species recorded from Vietnam. In 2022, Nguyen Thi My added ten species and one genus newly recorded for the Vietnamese termite fauna. In 2023, a new termite species, *Parrhinotermes molariserratus*, was discovered by Schiff et al. in Bidoup–Nui Ba National Park, Lam Dong Province, Vietnam. From 2021 to 2025, we conducted several survey projects to investigate and collect additional termite specimens in various national parks and nature reserves, resulting in the recognition of several species newly recorded for Vietnam; however, these species have not yet been formally published. In this study, we synthesize all previously recorded termite species together with the new records obtained from our supplementary surveys to provide an updated overview of the termite fauna of Vietnam and to establish a scientific basis for future studies on termite taxonomy, biology, and ecology.

## KUNIO TSUNODA MEMORIAL LECTURE

### Understanding the prey composition and life history of Chinese pangolins to enhance ex situ conservation strategies



Nick Ching-Min Sun  
Institute of Wildlife Conservation, National Pingtung University of Science and Technology,  
Taiwan

The Chinese pangolin (*Manis pentadactyla*) is a Critically Endangered, obligate myrmecophagous mammal native to the subtropical regions of southern and eastern Asia. A recent analysis of fecal samples identified 4 termite species and 58 ant species; together, termite and ant taxa accounted for nearly half of the total consumed prey biomass. Notably, the fungus-growing termite *Odontotermes formosanus* constituted the largest single contribution (40.8%). Field observations indicate that wild populations exhibit a distinct mating season spanning December to July, with parturition primarily occurring between September and February. This reproductive phenology is likely driven by seasonal variations in prey availability, as the activity patterns of termite and ant colonies correlate closely with climatic factors. While captive breeding and reintroduction programs are vital conservation strategies, current efforts primarily focus on the development of artificial diets. However, recent research highlights marked discrepancies in reproductive and growth traits between captive and wild individuals. Specifically: (1) captive individuals do not exhibit the seasonal breeding patterns observed in the wild; (2) captive-born neonates are significantly longer and heavier than their wild counterparts; and (3) captive pangolins undergo more rapid weight gain. This accelerated growth is likely associated with the high caloric density of artificial diets. To refine ex situ conservation strategies, future research must prioritize the optimization of artificial diets by accounting for seasonal fluctuations and the specific nutritional profiles of natural prey. Furthermore, captive management and reintroduction protocols should be adjusted to mitigate obesity risks and foster reproductive cycles that more closely mirror natural biological rhythms.

## KUNIO TSUNODA MEMORIAL LECTURE

### Friend or foe: the Formosan subterranean termites



Sang-Bin Lee  
Department of Biological Sciences, Pusan National University,  
Republic of Korea

The Formosan subterranean termite (FST), *Coptotermes formosanus* Shiraki, is probably the most extensively studied termite species in the world due to its significant economic impact in urbanized areas of the United States, Japan, southern China, and Taiwan. The FST is native to Taiwan and southern China and it has successfully invaded other regions, including the United States and, more recently, Israel, where it poses a serious concern to homeowners. Because of the severe and widespread damage, it causes to buildings, the FST has been listed among the 100 worst invasive species by the IUCN. Considerable efforts have been given to the control and management of the FST, leading to major advances in termite management strategies. Ironically, however, this highly destructive species has also provided exceptional research opportunities for termitologists. Research on the FST has greatly improved our understanding of how chitin synthesis inhibitor (CSI) baits work to eliminate the colony, as well as how subterranean termites excavate complex underground tunnel networks and organize collective foraging behavior. In this presentation, I will discuss how studying the most destructive termite species has significantly advanced our fundamental and applied knowledge of termite biology, behaviors, and controls, and how these insights continue to shape modern termite management practices.

## KUNIO TSUNODA MEMORIAL LECTURE

### **From Solitary Insect to Social Colony: Genomic Remodeling of Sensory Receptors in Termite Sociality**



Bosheng Chen  
A&F University, Hangzhou,  
China

Sociality is a relatively special form of insect living mode, which contains evolved behaviors such as brood caring, nest defending, corpse burring, and reproductive dividing of labor. By integrating these altruistic behaviors, social insects (ants, bees, wasps, termites, and even eusocial aphids and thrips) achieve to develop high robustness and resilience colonies to the dynamic changing environment. Such characteristics has led interest to the causes and consequences in the evolution of sociality within eusocial insects, and hence offer a window into addressing the abiding questions of how novelty arises in the biological evolution. Emerging evidences indicate that the increasing of insect sociality could correlated with the increased brain size and enhanced information-processing ability, which let eusocial species manage to handle more diverse internal and environmental stimulus. However, because of the large number and diversity of neurons and synapses exist in the brain, it is still remaining challenge to mapping onto social behaviors. Comparatively, as the front-end of the brain-generate behaviors, sensory system of eusocial insects and their correlated mediators is a viable entry point to unveil the biological and evolutionary properties of the complex insect social behavior. Here, we conducted a comprehensive genomic investigation of key chemosensory organs dissected from workers of the termite *Coptotermes formosanus*, systematically characterizing the distribution, evolutionary dynamics, and functional diversification of major receptor families, including odorant receptors (ORs), gustatory receptors (GRs), and ionotropic receptors (IRs) across the order Blattodea. These findings illuminate the profound genomic remodeling of sensory systems that accompanies the evolutionary transition from solitary to highly social lifestyles in termites.

## DONALD EWART MEMORIAL LECTURE

### Expansion of *Incisitermes minor* into Pacific Rim Countries



Partho Dhang  
Partho Dhang Consultancy, 2410 Belarmino Street, Makati City,  
Philippines

Termites are invasive in nature, which means after entering a new territory they are capable of invading into native habitats, i.e. beyond human-modified environment such as buildings, and cultivated crops. The principal parameter required in the process of invasion is time. Seven of 28 invasive termite species known till date are Kalotermitids or drywood termites (Evans, et al, 2013). It is thought that drywood termites have crossed oceans at least 40 times in the past 50 million years, more than any other termite group. Interestingly islands/island nations have the most invasive species, especially those in the Pacific Ocean (13 species) and the Caribbean Sea (9 species). Indications are *Incisitermes minor* might have spread to more Pacific Rim territories than presently reported. Also, in countries where it is being newly reported, its spread might be more extensive and deeper than observed. Most countries in the Pacific Rim are small and low in GDPs and may lack resources, expertise and appropriate method of control which include structural fumigation. Thus, the economic importance of this species is immense in this region.

## **ORAL LECTURE SESSION S1**

# **TERMITE BIOLOGY: BIODIVERSITY, EVOLUTION, AND PHYSIOLOGY**

## [O\_01] A new species of subterranean termite in the genus *Reticulitermes* from southern California

Chow-Yang Lee\*, Joanne Tzu-Chia Chen

Department of Entomology, University of California, Riverside, CA 92521, USA

\*Corresponding author, email: chowyang.lee@ucr.edu

### Introduction

The taxonomy of subterranean termites in the genus *Reticulitermes* in California has long been controversial due to morphological conservatism, overlapping distributions, and discordance among genetic markers. Historically, only *Reticulitermes hesperus* Banks and *Reticulitermes tibialis* Banks were recognized in the state (Light and Pickens 1934). However, chemo-taxonomic, behavioral, and molecular studies have repeatedly suggested the presence of additional cryptic species (Haverty and Nelson 1997; Haverty et al. 1999; Tseng et al. 2023).

In particular, cuticular hydrocarbon (CHC) phenotypes SC-B and SC-B' from southern California have been consistently identified as candidate undescribed taxa. Here, we apply an integrative taxonomic approach to describe *Reticulitermes rusti* Chen sp. nov., corresponding to these CHC phenotypes (Chen et al. 2025). By combining mitochondrial DNA phylogenetics, genetic clustering analysis, morphometric analyses, and ecological data, we provide strong evidence that *R. rusti* represents a distinct biological species sympatric with *R. hesperus*.

### Materials and methods

Specimens were collected throughout California between 2005 and 2024, with sampling concentrated in southern California, including urban, suburban, and natural habitats. Termites were obtained from decaying wood, tree stumps, fallen branches, and infested structures, as well as from in-ground monitoring stations. Individuals were preserved for molecular and morphological analyses, with particular emphasis on sampling workers for DNA extraction and soldiers and imagoes for morphometric measurements.

To assess phylogenetic relationships, partial sequences of three mitochondrial loci, 16S rRNA, cytochrome c oxidase subunit I (COI), and cytochrome c oxidase subunit II (COII) were sequenced. These loci were then concatenated and supplemented with sequences from GenBank and prior studies to place California lineages in a broader context. The phylogeny was built using maximum-likelihood inference. To evaluate whether mitochondrial lineages represented distinct genetic clusters within sympatric areas, we genotyped individuals from sympatric areas using seven microsatellite loci. Genetic clustering was assessed using both Principal Coordinates Analysis (PCoA) and Bayesian clustering (STRUCTURE). Morphological differentiation among species was assessed through detailed morphometric measurements of soldiers and imagoes, encompassing multiple head, pronotum, mandible, and wing characters.

### Results and Discussion

Phylogenetic analyses showed five *Reticulitermes* clades in the western United States. Three occurred in southern California and corresponded to *R. hesperus*, *R. tibialis*, and a distinct lineage associated with CHC phenotypes SC-B/SC-B', herein described as *R. rusti*. Mitochondrial divergence between *R. rusti* and *R. hesperus* was substantial ( $\approx 7.5\text{--}8.0\%$  for COI and COII),

exceeding commonly used species-delimitation thresholds. Despite morphological similarity of the soldier caste to *R. hesperus*, *R. rusti* was genetically closer to *R. tibialis*.

Genetic clustering analyses revealed three distinct genetic clusters in southern California: *R. rusti*, and northern and southern populations of *R. hesperus*. No widespread admixture was detected, even in sympatric areas, and population assignment tests achieved 98% accuracy, supporting reproductive isolation.

Morphological differentiation varied by caste. Soldier characters overlapped extensively between *R. rusti* and *R. hesperus*, although multivariate analyses detected significant size differences. Soldiers of *R. rusti* were readily distinguished from *R. tibialis* by head-to-mandible ratios and mandible shape. In contrast, imagoes provided clearer diagnostic traits: *R. rusti* imagoes possess darker tibiae and significantly longer wings than *R. hesperus*.

Ecological data further support species status. *Reticulitermes rusti* is widespread in southern California and overlaps geographically with *R. hesperus*, but differs in swarming phenology, with flights occurring primarily from late fall to winter rather than spring. This temporal separation likely contributes to reproductive isolation.

The formal description of *R. rusti* resolves a long-standing taxonomic ambiguity and confirms decades of chemotaxonomic and genetic evidence. Recognition of this species has important implications for termite ecology and structural pest management in California. Although *R. hesperus* has historically been regarded as the dominant subterranean termite pest in the state, some pest records may reflect misidentifications of *R. rusti*. The species is named in honor of Professor Emeritus Michael K. Rust for his foundational contributions to termite biology in southern California.

## References

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## [O-02] Combining ecology, genomics and ontogeny to define sociality in termites

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### Introduction

The transition from solitary individual to society is referred to as a major evolutionary transition (MET, Smith and Szathmary, 1995). In the Blattodea, one MET gave rise to a spectacular radiation of social termites, boasting an array of morphologically distinct social castes including various worker, soldier and reproductive phenotypes (Revely et al., 2024; Roisin, 2000) and a wide diversity of ecological traits. Although the increased social complexity of termites compared to solitary and subsocial cockroach relatives is self-evident, debates have broken out over where and how the line representing a MET should be drawn but little consensus has emerged (Boomsma and Gawne, 2018; Crespi and Yanega, 1995; Sherman et al., 1995). More recently, a multivariate approach to define sociality has been used to identify how ecological traits tie to reproductive correlates of sociality (Revely et al., 2024). Such a method is relevant to consider the different dimension of social complexity portrayed by caste polyethism, colony size, nest complexity, genomic architecture, or again ontogenic plasticity (Kapheim et al., 2015; Miura et al., 1998; Pull and McMahon, 2020; Revely et al., 2024). We adopted such an approach to investigate the nature of sociality on 29 species of termites and cockroaches, for which high quality genomes have recently been sequenced. As our starting point, we identified 4 a priori categories of sociality: solitary cockroaches, sub-social *Cryptocercus*, and termites with linear or bifurcated ontogeny. We analysed correlations between several ecological, genomic and ontogenic traits and these a priori categories of sociality, showing how these traits characterise distinct aspects of sociality. This demonstrates the power of such a multivariate approach for understanding social complexity in the Blattodea.

### Material and Method

We retrieved from the literature information on the ontogeny, caste number, colony size, diet, nesting type, foraging behaviour, protist occurrence, genome size and gene number and established social estimates of termites and cockroaches. In brief, we formatted all ontogenies as a directed network of instar development of mature colonies for male and female separately using the ontogeny of the closest relative when necessary. Using these networks, we calculated the characteristic path length (Boccaletti et al., 2006) to estimate quantitatively ontogenic complexity. Smaller values of CPL indicated more bifurcated networks reflecting an ontogeny leading to more terminal caste. We used the ratio of CPL on the number of terminal castes to obtain an Ontogenic Complexity Metric (OCM) which consider both ontogeny and polyethism. Colony size was computed as the logarithm of the upper range found in the literature and diet was classified as wood or soil feeding. We explored correlations between these trait values using Pearson correlation coefficient (PCC). We examined how covariates correlated with the 4 a priori categories of social organisation using general linear models and Tuckey test. 2

### Results and Discussion

We found strong correlations between the social categories, CPL, OCM, colony size, number of terminal caste and ontogeny type but with some variation (PCC range: 0.42 – 0.88, median: 0.73) highlighting the importance of these traits as core social traits and the different dimensions of

sociality they cover. Further, other traits were strongly correlated with some of the later but not all, justifying a multivariate approach. Indeed, foraging behaviour was not correlated with social category or the number of terminal castes but was positively correlated with ontogeny type (PCC = 0.63), OCM (PCC = 0.38), and colony size (PCC = 0.50). Therefore, foraging outside the nest and colonising new resource is more likely in species with large colonies and a dedicated workforce (Roisin and Korb, 2010). As expected, nesting type was highly collinear with social category, ontogeny type and colony size (Shellman-Reeve, 1997) but not with caste number (PCC = 0.35). Diet and presence of gut protists were not collinear with any social trait (PCC < 0.38, median: 0.22) but were expectedly correlated (PCC = -0.61). Presence of gut protists was also collinear with nesting type, and foraging behaviour. Moreover, we found that some traits better characterised certain levels of social complexity than others. Genome size and gene number were distinctively lower in termites and *Cryptocercus* compared to solitary cockroaches, as previously found (Liu et al., 2025), and OCM values were significantly higher in termites with bifurcated ontogeny (Tukey:  $t_{25} = -4.21$ ,  $P = 0.002$ ) where within-group variation was high. Finally, CPL values were higher for termites with linear pathway compared to bifurcated ones (Tukey:  $t_{25} = 4.99$ ,  $P < 0.001$ ) reflecting how the early ontogenic bifurcation acts as a significant shortcut to reach terminal castes which is, from a network perspective, more efficient than the regressive moults of termites with linear pathway.

### Conclusion

Our study reveals that ecological, ontogenic and genomic shifts can provide an ideal framework to the study of different dimension of social complexity in Blattodea. Most notably, we found core traits to define social complexity and traits, such as foraging behaviour or nesting type, permitting to explore additional aspects of sociality. Overall, applying a multivariate approach to study sociality on this subset of species is a promising avenue to get a deeper resolution to the actual social complexity in Blattodea.

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## [O\_03] Unraveling termite evolution with high-resolution genome assemblies

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### Introduction

Termites are primarily known for their social lifestyle and wood-feeding habits. They are one of the most abundant animal taxa in tropical and subtropical terrestrial ecosystems, where they are the primary decomposers of plant organic matters from sound wood to humus and soil. The reference genomes of nine termite species have been published previously, including genomes of four of the 13 termite families and two of the 18 subfamilies of Termitidae, hindering our understanding of termite genome evolution. Here, we generated genome assemblies for 45 termite species, covering 11 of 13 termite families and 12 of 18 Termitidae subfamilies, and two cockroaches (*Blatta orientalis* and *Cryptocercus meridianus*). Our results shed new light on termite genome evolution.

### Material and Method

We sequenced 45 genomes of termite species belonging to 11 termite families and 12 subfamilies of Termitidae, as well as the genomes of two cockroach outgroups, *Blatta orientalis* and *Cryptocercus meridianus*. For each species, we sequenced PromethION long-read sequences, which we used to generate the initial assemblies. We also sequenced short reads for genome polishing, and between one and nine transcriptomes per species for genome annotation. Finally, we generated Omni-C and Hi-C data for the two cockroach species and 24 termite species, which we used to scaffold our genomes. All bioinformatic analyses were performed as described in Liu et al. 2025a, 2025b, 2025c.

### Results and Discussion

Our comparative genomics analyses showed that the common ancestor of termites and *Cryptocercus* possessed a small genome compared to other cockroaches, indicating that genome size reduction predated the origin of eusociality in termites (Liu et al. 2025a). Genome shrinkage was followed by a re-expansion during the early evolution of Termitidae, the most speciose family of termites (Liu et al. 2025a). Our results also show that termites continuously acquire genes by horizontal transfer, primarily from Wolbachia, which they quickly lose, leaving very few horizontally acquired genes conserved across termite lineages and indicating that horizontal gene transfer is largely a non-adaptative process in termites (Liu et al. 2025b). Lastly, we characterized the transposon landscape of termites and identified 37,966 transposon families, which we use to reconstruct phylogenetic trees with an accuracy comparable to phylogenies inferred from thousands of single-copy protein-coding gene sequence alignments (Liu et al. 2025c). Overall, our

sequencing effort multiplied the number of available termite reference genomes by six and provided an unprecedented insight into the termite genome evolution.

### **Conclusion**

Termites have historically received less attention from researchers than social insects belonging to Hymenoptera, which include bees, ants, and wasps. Their genomes have also been comparatively less studied. In this study, we sequenced, annotated, and compared the genome characteristics of 45 termite species representing the ecological and taxonomic diversity of termites, including 11 of the 13 extant families and 12 of the 18 extant subfamilies of Termitidae. We also sequenced two cockroach outgroups, *Blatta orientalis* and *Cryptocercus meridianus*. Our results expanded the genomic resources of termites and shed new light on their genome evolution.

### **Acknowledgement**

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## [O\_04] The evolution of visual opsin genes in termites

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### Introduction

Insects are the most diverse group of animals and occupy a wide range of photic niches. The remarkable diversity of eye morphology and extensive variation in visual gene repertoires highlight the critical role of vision in insect evolutionary success (Marcionetti et al. 2024). Within the phototransduction cascade, the pathway that converts light into cellular signals, visual opsins are responsible for light perception and exhibit great variability across species compared with other components of the pathway (Guignard et al. 2022). While visual opsins are often massively duplicated in species with well-developed vision and show decay or loss in blind species, the evolutionary fate of vision-related genes in species exhibiting eye polymorphism across different photic niches remains poorly explored (McCulloch et al. 2022). Termites are particularly well suited to address this question: reproductive alates possess well-developed eyes but use them only briefly during swarming and tandem running (Mizumoto and Bourguignon 2023), whereas other castes, such as larvae, workers, and soldiers, are largely blind and lack ocular organs.

### Material and Method

To investigate the evolutionary dynamics of visual genes in termites, we systematically screened for visual opsin genes across 45 termite genomes generated in our recent publication (Liu et al. 2025). Identified opsin sequences were annotated and subjected to comparative and selection analyses to assess patterns of conservation, diversification, and potential relaxation of selective constraints, thereby evaluating whether vision remains an important sensory modality in termites. In addition, we examined opsin gene expression profiles across different developmental stages and castes to further elucidate the functional roles of visual opsins in caste-specific contexts and to assess how visual requirements vary throughout the termite life cycle.

### Results and Discussion

Our analyses reveal complex and lineage-specific evolutionary trajectories of visual opsin genes in termites, despite the widespread reduction or absence of functional eyes in most castes. Two long-wavelength sensitive opsins, LW2a and LW2b, are largely conserved across termites, but the loss of LW2b in the prototermite cockroach *Cryptocercus meridianus* and several basal termite lineages closely coincides with the absence of ocelli, supporting a specific association between LW2b and ocellar function (Guignard et al. 2022). Given that LW2b is thought to facilitate vision under high-light conditions, its loss in ocellus-free species is consistent with relaxed visual demands. In contrast, LW2a is universally present and shows a distinct evolutionary pattern. Although LW2a and LW2b are typically arranged in a tandem array, this linkage is disrupted in a subset of Termitidae, coinciding with increased gene duplication and genome expansion. Most duplicated fragments are truncated and lack complete opsin domains, indicating selection against maintaining multiple full-length copies. Consistent with this, selection analyses reveal relaxed selection across termites overall but intensified and often positive selection in the LW opsin-unlinked clade, suggesting episodic functional divergence rather than simple degeneration. Notably, signals of positive selection and expression levels of LW2a and LW2b are often mutually exclusive across lineages, further supporting functional differentiation between the two genes. Our expression analyses reinforce this pattern, with different termite clades showing dominance of

either LW2a or LW2b expression, and in some cases near-exclusive expression of a single opsin in specific castes. Compared to LW opsins, UV opsins exhibit consistently high expression across nearly all species and castes, including those that are completely blind, and show broadly distributed signals of positive selection. Together, these results suggest that while classical visual functions have diminished in termites, opsin genes have been retained and shaped by selection for alternative non-ocular functions.

### **Conclusion**

In this study, we present, to our knowledge, the first genomic and gene expression analysis of visual opsin genes in termites. Our findings show that visual opsin gene repertoire is largely conserved across termite and cockroach species and matches eye morphology. Selection analyses reveal that visual opsin genes are subject to varying selection pressures, with evidence of strong positive selection in many lineages. Finally, we demonstrate that these genes are expressed across different life stages and castes in nearly all examined termite species, suggesting the functionality of visual opsins in the blind termite castes and potentially pleiotropy in termites.

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## [O\_05] Exploring the Mechanism by Which Iontropic Receptor IRx Regulates Humidity Sensing Behavior in *Coptotermes formosanus*

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### Introduction

*Coptotermes formosanus* Shiraki (Blattodea: Rhinotermitidae), a typical eusocial insect widely distributed in China and primarily inflicts damage on the wooden structures of buildings and garden trees. Annually, termite infestations cause over 1 billion dollars in economic losses in China, with *C. formosanus* being one of the most destructive species. Therefore, research on the green prevention and control of *C. formosanus* holds significant practical value.

The sensory system of insects is crucial to adapt to complex odor environments and sustain vital activities. Insect sensory receptors are mainly classified into three types: Odorant Receptors (ORs), Gustatory Receptors (GRs), and Iontropic Receptors (IRs). To date, several studies have been identified the function of termite ORs and GRs. However, the characteristics of IRs and their potential functions in termite species is still known. The present study focuses on unveil the gene copy number, sequence properties, and potential functions of ionotropic receptors in isopteran species (i.e., termites).

Through transcriptomic data mining and gene sequence alignment, a total of 11 open reading frames (ORFs) encoding ionotropic receptor genes were identified. The functions of CforIRs were validated in vivo via RNA interference (RNAi) technology. The results demonstrated that CforIRC1, CforIRC2, and CforIRC3 are associated with humidity sensing in *C. formosanus*. After silencing these three genes, the attractiveness of water to *C. formosanus* was significantly attenuated. This study reveals the potential role of ionotropic receptor genes in the humidity-sensing mechanism of *C. formosanus*, which provides a theoretical basis for developing novel control strategies against this termite species.

### Material and Method

#### Insect rearing

*Coptotermes formosanus*, were reared in a dark room, with a controlled temperature of  $25 \pm 3$  °C and a relative humidity (RH) of  $70\% \pm 10\%$ .

#### Iontropic receptors identification and construction of phylogenetic tree

To identify ionotropic receptors (IRs) in the Formosan subterranean termite (*Coptotermes formosanus*) and several other termite species, we first compiled a local IR database comprising known IR sequences from model insects, including *Drosophila melanogaster*, *Apis mellifera*, and *Bombyx mori*. Transcriptome assemblies from antennal and maxillary palp tissues of *C. formosanus*, along with additional *C. formosanus* transcriptomic datasets, were then queried against this custom IR database using Bitacora. Hits were further screened for the presence of conserved ionotropic receptor domains (Pfam PF00060 and PF10613). Incomplete sequences shorter than 600 bp were discarded. The retained sequences were aligned using MAFFT, trimmed with ClipKIT, and used to construct a phylogenetic tree with FastTree under the LG substitution model (with 200 bootstrap replicates).

### RNAi experiment

First, interference primers were designed based on the NCBI database, followed by PCR amplification and agarose gel electrophoresis. Subsequently, the PCR products were recovered, and double-stranded RNA (dsRNA) was synthesized using the gel-purified products. Finally, dsRNA was introduced into the bodies of *Coptotermes formosanus* with a microinjector, and the feeding method was adopted in this experiment.

### Results

Phylogenetic analysis of ionotropic receptors (IRs) in Blattodea revealed that this order's IR repertoire can be divided into eight distinct subfamilies. Three of these subfamilies (Blattodea IR groups 1–3, Figure 1A) are exclusive to Blattodea, whereas the remaining subfamilies have orthologs in other insect orders. This pattern indicates that Blattodea has evolved lineage-specific IRs adapted to its unique ecological and behavioral traits, although whether these receptors have acquired novel or modified functions remains unclear.

Notably, the German cockroach (*Blattella germanica*) possesses a substantially larger number of IRs than termite species, particularly within Blattodea IR group 2 (Figure 1A). This expansion likely reflects adaptive evolutionary pressures in *B. germanica* for enhanced environmental sensing, suggesting that this subsocial species may exhibit greater sensitivity to abiotic cues (e.g., temperature, humidity, and ionic composition) compared to termites. In contrast, termite genomes show no significant IR expansion relative to the subsocial German cockroach, implying that the transition to advanced eusociality in termites did not involve the proliferation of novel IRs specifically dedicated to regulating social behaviors. We observed that several IR subfamilies exhibit remarkable sequence conservation across Blattodea (e.g., Blattodea IR group 1), with little variation in gene copy number. Given this high degree of conservation—reminiscent of the odorant receptor co-receptor (Orco)—we hypothesize that these subfamilies fulfill essential, ancestral functions. Accordingly, we selected representative IRs from these conserved lineages in *Coptotermes formosanus* for subsequent functional validation.

Through a series of RNAi and behavioral assays, we found that knockdown of the IR1C gene in *Coptotermes formosanus* significantly attenuated the strong hygrotaxis exhibited by worker termites, which normally aggregate predominantly in moist areas (Figure 1B). Following effective suppression of dsIR1C expression (Figure 1C), workers displayed an approximately equal distribution between moist and dry zones, with the loss of moisture preference becoming evident within just 30 minutes (Figure 1D). These results indicate that IR1C is likely a key gene regulating humidity perception in *C. formosanus*. However, whether IR1C requires heterodimerization with other receptors—similar to the odorant receptor co-receptor (Orco)—to exert its function remains unknown.

### Conclusion

In this study, we identified ionotropic receptors (IRs) across Blattodea genomes using a custom-built IR database. Phylogenetic analysis revealed several highly conserved IR subfamilies unique to this order. We then performed RNAi-mediated knockdown of a representative IR from one such conserved subfamily in the Formosan subterranean termite (*Coptotermes formosanus*). Behavioral assays following dsRNA treatment demonstrated that silencing the IRC1 ortholog significantly impaired humidity preference in worker termites, with dsIRC1-treated individuals exhibiting clear deficits in selecting moist environments.

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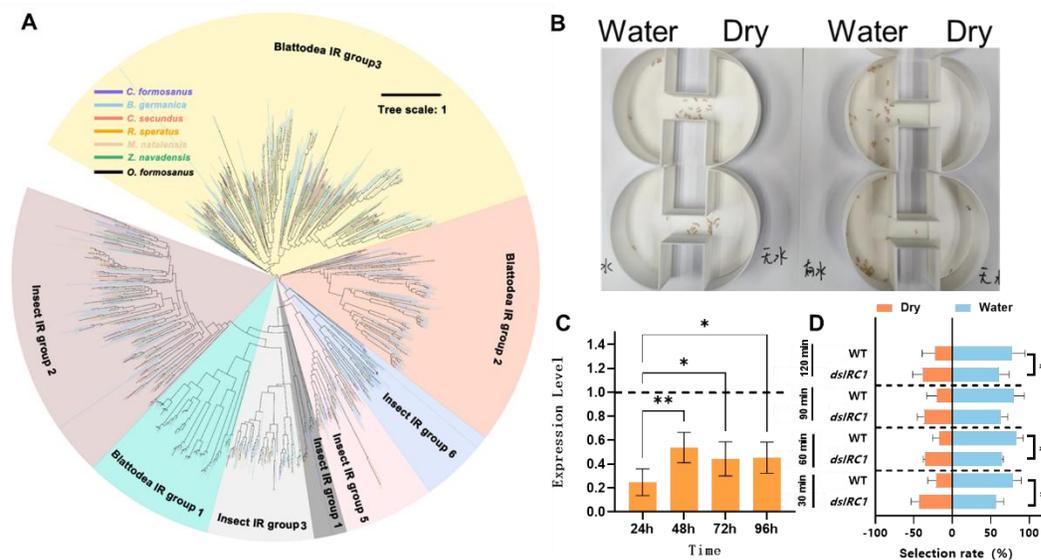


Figure 1. Functional analysis of ionotropic receptors (IRs) in Blattodea insects.

(A) Phylogenetic tree of IRs in Blattodea, showing that IRs from various termite species and the German cockroach (*Blattella germanica*) are classified into eight distinct subfamilies. (B) Humidity preference assay in *Coptotermes formosanus* workers following RNAi treatment. The experimental arena is a 3D-printed behavioral testing device with semicircular zones on the left and right sides containing filter paper—one moistened with water (left) and the other dry (right). Wild-type (WT) or RNAi-treated termites were released in the central zone, and the proportion of termites in each side was recorded at regular intervals. (C) Validation of IR knockdown efficiency by RNAi treatment, showing relative expression levels of targeted IR genes. (D) Statistical analysis of preference for the moist zone in *C. formosanus* workers following knockdown of the IRC1 receptor. Variation analysis were performed by one-way ANOVA followed by Tukey post hoc test (C) and Mann-Whitney U test (D). \*,  $p < 0.05$ ; \*\*,  $p < 0.01$

## [O\_06] Functional Analysis of Antifreeze Proteins AFPs in the Cold Tolerance of *Reticulitermes flavipes*

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### Introduction

Insects have evolved diverse strategies to survive low temperatures. As the most widely distributed termite species in China, *Reticulitermes flavipes* remains poorly studied regarding its physiological and molecular mechanisms of cold adaptation. In particular, its molecular responses to cold stress have yet to be clearly elucidated. This study focuses on antifreeze proteins (AFPs) and examines their functional roles during cold adaptation in *R. flavipes*.

### Materials and Methods

Worker termites of *Reticulitermes flavipes* were collected from a natural park in Lin'an, Zhejiang Province, China. After treatment at -2, 0, 2, 6, 15, and 27°C (control group), total RNA was extracted from the whole body of workers. The HiScript II 1st Strand cDNA Synthesis Kit (Vazyme, Nanjing, China) was used to synthesize cDNA from 2µg of RNA samples. AFP genes were amplified by PCR and DNA products were examined via 1.5% agarose gel electrophoresis. The relative expression levels of six AFP candidates (AFP1–AFP6) were quantified using qRT-PCR on a CFX96 Real-Time PCR System.

A specific dsRNA targeting AFP3 (156 bp) was synthesized in vitro using the T7 High-Yield Transcription Kit for RNA interference (RNAi). dsRNA was designed to specifically silence AFP3 expression. Individuals treated with dsAFP3, dsGFP were subjected to cold exposure, and knockdown rates were recorded for functional assessment. Insects that were unconscious and incapacitated but still had active limbs were recorded as knockdown insects. Knockdown rate (%) = number of individuals knocked down/total number of insects tested \*100%.

### Results

Expression patterns of AFP1–AFP6 under low-temperature conditions

We used RT-qPCR to quantify gene expression levels of termite AFPs, using 27 °C as the control condition, assessed the relative expression profiles of the six AFP candidates under -2, 0, 2, 6, 15°C of cold stress. The results (Figure 1) revealed pronounced differences among these genes. Among these, AFP3 exhibited the strongest and most specific induction, which expressed at 0 °C and showed 11-fold change that workers in control group ( $p < 0.001$ ). Although AFP2, AFP5, and AFP6 also showed moderate upregulation at 0 °C, their induction magnitudes were markedly lower than that of AFP3. In contrast, AFP1 and AFP4 exhibited inconsistent or minimal upregulation, indicating weaker specificity to cold stress. Functionally, AFP3 represents the most cold-responsive gene among all candidates.

#### Functional validation of AFP3

To evaluate the role of AFP3 in termite cold tolerance, RNAi-treated termites were exposed to -2 °C condition and their knockdown rates were monitored over time. As shown in Figure 2, silencing AFP3 significantly reduced cold tolerance. After 24 h maintaining at -2 °C, the knockdown rate of the dsAFP3 group ( $36.67 \pm 2.89\%$ ) was significantly higher than that of the control groups ( $p < 0.05$ ). This result confirmed that AFP3 involved in cold resistance process of *R. flavipes* workers.

After 36 h, the dsAFP3 group reached a knockdown rate of approximately 75%, again significantly higher than controls ( $p < 0.05$ ).

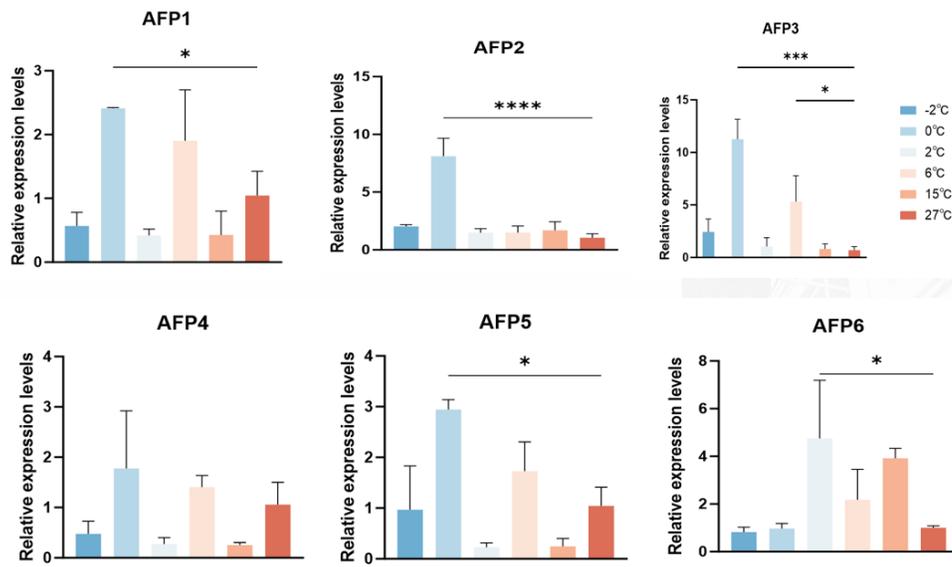
### Conclusion

Our results demonstrate that AFP genes (especially the AFP3 gene) are significantly upregulated cold resistance of *R. flavipes*. RNA interference of AFP genes leads to markedly increased knockdown rates and reduced activity levels after cold exposure, confirming that AFPs play a crucial role in cold tolerance. These findings provide strong evidence for the involvement of AFPs in the molecular mechanisms underlying cold adaptation in *R. flavipes*.

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Figure 1. Relative expression levels of AFP1–6 in *Reticulitermes flavipes* workers



## **ORAL LECTURE SESSION S2**

### **TERMITE BIOLOGY: BEHAVIOUR ECOLOGY**

## [O\_07] Elevational intraspecific body size patterns in termites depend on feeding habits

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### Introduction

Termites are major forest decomposers (Martius 1997, Jouquet et al. 2011) and key protein sources (Li et al. 2011). Body size of termites impacts food selection, colony population, and nest size (Eggleton et al. 1998, Korb 2008). Termite body size is influenced by evolutionary history and developmental pathways (Mizumoto and Bourguignon 2021), with factors such as temperature and colony structure driving differentiation (Chown and Gaston 2010, Lin et al. 2024). Body size variation along elevational gradients was recently report in a fungus-growing termite species (Lin et al. 2024), but the consistency of this pattern across termite taxa remains uncertain.

This study assesses altitudinal body size variation across distinct feeding groups: drywood termites (Kalotermitidae), subterranean termites (Heterotermitidae), wood-feeding and fungus-growing termitids (Termitidae). By focusing on these species within a fixed latitude, we aim to assess the generality of this variation and elucidate the potential ecological and physiological mechanisms driving these patterns.

### Material and Method

We surveyed the National Taiwan University Experimental Forest and collected 952 termite specimens from 132 sites along an elevational gradient of 259–1,917 m. Four species, *Odontotermes formosanus* (Shiraki), *Nasutitermes parvonasutus* (Nawa), *Reticulitermes kanmonensis* Takematsu, and *Glyptotermes satsumensis* (Matsumura) were selected for morphometric analysis of workers and soldiers. For each individual, four traits were measured: head width, pronotum width, number of antennal articles, and left mandible length (soldier of *Nasutitermes* using head length instead).

To examine how morphological traits vary with altitude, we performed a multivariate analysis of variance (MANOVA) using R (version 4.3.2; R Core Team, 2023). The MANOVA tested the effects of altitude, antennal article number, and their interaction on three traits: head width, pronotum width, and left mandible length. Model significance was evaluated using Pillai's trace, which is robust to deviations from multivariate normality and unequal variances.

### Results and Discussion

Body size increases with altitude in the soldier and worker castes of *O. formosanus* and *R. kanmonensis*, as well as in the soldier and major worker castes of *N. parvonasutus*. The minor workers of *N. parvonasutus* and all castes of *G. satsumensis* exhibit no significant change in body size with increasing altitude.

In each worker instar, individual with the same number of antennal articles, body size increases with altitude in *O. formosanus* and *R. kanmonensis*. In *G. satsumensis*, individuals of the same instar show no altitudinal size differences, except for workers with 14 antennal articles, whose size increases with altitude. Body size generally correlates with antennal number across species, excluding *R. kanmonensis* soldiers, *N. parvonasutus* was excluded from this analysis due to a lack of variation in antennal count. The number of antennal articles increases with altitude in *O.*

*formosanus* (soldiers and major workers) and *R. kanmonensis*, but decreases in *G. satsumensis* workers.

These findings suggest that termite species or castes that forage on the ground tend to exhibit larger body sizes at higher altitudes, whereas one-piece nesting species (e.g., *G. satsumensis*) or castes that remain within their nests show no such trend. We speculate that the discrepancy depends on whether the caste regularly encounters external environmental conditions.

The measurement data of body size also show allometric growth patterns: *O. formosanus* mandibles grow slower than the head and pronotum (negative allometry), while the *R. kanmonensis* pronotum grows faster than the head and mandibles (positive allometry). This may be due to the high energy cost of mandible growth or an increased need for thoracic strength at high altitudes, but these inferences require confirmation.

### **Conclusion**

This study reveals that altitudinal body size variation is not universal and appears to be modulated by nesting habits and foraging behavior. Moreover, allometric growth was detected in the mandibles or pronotum of *O. formosanus* and *R. kanmonensis*, though the mechanisms driving this phenomenon remain unclear.

### **Acknowledgement**

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## [O\_08] Machine Learning-Based Assessment of Termite Distribution and Climate-Driven Range Shifts in China

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### Introduction

Understanding the geographical distribution of termites and the environmental factors that shape their habitat suitability is essential for predicting potential expansion trends and assessing ecological risks under global climate change. Termites play a vital role in terrestrial ecosystems, participating in nutrient cycling, soil formation, and the decomposition of organic matter. However, some termite species can also cause substantial economic losses in forestry, agriculture, and urban environments (Barca et al., 2018). Therefore, accurately predicting their potential distribution is of great significance for both ecological research and pest management.

This study aims to investigate the future distribution patterns of termites in China and identify the dominant environmental factors controlling their spatial dynamics. To accomplish this, we collected recent termite occurrence records (Cai and Huang, 1979; Huang et al., 1992; Yong et al., 2025; Cheng et al., 2014) and combined them with multi-source environmental datasets. These included bioclimatic variables generated from global climate models, the Normalized Difference Vegetation Index (NDVI), soil type, topography, and other relevant ecological layers. Furthermore, based on the collected database, we conducted a machine learning analysis of termite distribution across China using four distinct algorithms: Support Vector Machine (SVM), Random Forest (RF), Extreme Gradient Boosting (XGBoost), and Convolutional Neural Networks (CNN). These models have shown wide applicability in ecological niche modeling due to their ability to capture nonlinear relationships between species distribution and environmental variables. Using these comprehensive datasets, we constructed predictive models to map termite distribution and assess future expansion trends under projected climate scenarios.

### Materials and Methods

To evaluate the predictive performance of different modeling techniques, we constructed four machine learning models—SVM, CNN, RF, and XGBoost—using termite occurrence data and environmental predictor variables. The data were randomly split into training and test sets (8:2), and model parameters were tuned to achieve optimal performance. The accuracy of models was estimated by metrics including Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Area Under Curve (AUC), and overall classification accuracy.

Using the optimized model, we predicted the distribution of both total termite populations and soil-nesting termites. Predictions were generated for three temporal scales: current distribution, distribution in ten years later, and fifty years later in the future based on climate change projections. Spatial patterns were visualized and analyzed to identify potential areas of expansion and contraction.

### Results and Discussion

Our results indicate that XGBoost provides the highest accuracy in predicting termite distribution across China (Figure 1a-d). In continuous variable prediction, XGBoost achieved an RMSE of 0.178 and an MAE of 0.0020, significantly lower than those of Random Forest (RMSE 0.0314,

MAE 0.0087), SVM (RMSE 0.0705, MAE 0.0168), and CNN (RMSE 12.2954, MAE 11.5416). In the classification prediction of a total of 4,000 sample points on both the northern and southern sides, XGBoost achieved an overall accuracy of 98.16%, also higher than models such as Random Forest, SVM, and CNN (Figure 1f).

The feature importance analysis based on the XGBoost model (Figure 1g) revealed that bio11 (mean temperature of the coldest quarter) and bio6 (minimum temperature of the coldest month) were the most influential predictors of termite distribution. These variables were followed in importance by ndvi8 (Normalized Difference Vegetation Index in August), bio12 (annual precipitation), bio7 (annual temperature range), ndvi1 (Normalized Difference Vegetation Index in January), and bio1 (annual mean temperature).

A notable finding is the consistent northward expansion trend predicted across future scenarios (Yong et al., 2025). Under projected climate warming, suitable habitats for termites are expected to expand toward higher latitudes and elevations. The model suggests that termite populations may gradually spread into Xinjiang Province, northeastern China, and parts of Inner Mongolia Province. Soil-nesting termites exhibit a similar pattern, with future expansion likely to include southern Shaanxi Province, the entirety of Shandong Province, and most regions of Henan Province.

These results highlight the significant influence of climate change on termite population dynamics. As temperature and precipitation patterns shift, regions previously unsuitable for termite colonization may become increasingly favorable. Such changes could have important ecological and economic implications, including increased risk of invasive termite outbreaks, forest damage, and impacts on soil properties. It is therefore crucial to incorporate climate projections into termite management strategies and ecological risk assessments.

### **Conclusion**

This study identifies key biological and environmental drivers that shape termite distribution across China. Temperature, humidity, and precipitation are essential for termite survival, while elevation of these factors significantly influences habitat suitability and species richness. By integrating advanced machine learning models with ecological knowledge, this research provides a robust framework for predicting termite distribution under current and future climate conditions. This model could be used to predict the termite distribution of other region if data is available.

Our future research will focus on optimizing machine learning models, conducting variable importance analyses, and exploring interactive effects among environmental factors. Additionally, assessing the impact of climate warming on termite expansion will be crucial for understanding future ecological risks. The findings of this study contribute valuable insights into termite ecology and provide reliable technical support for biodiversity conservation, pest management, and ecological forecasting.

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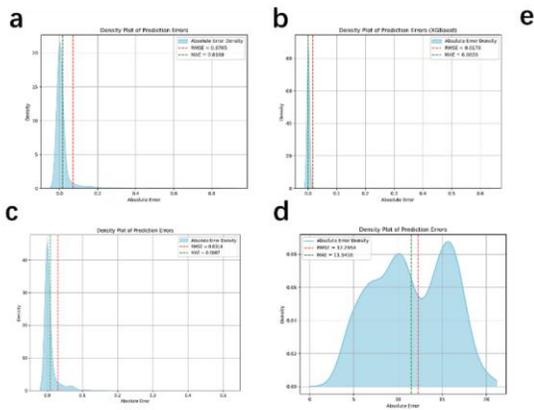


Figure 1 **a-d**: Prediction error density plots and RMSE and MAE values for SVM, XGBoost, Random Forest, and CNN models. **e**: Spatial distribution map of sampling points for model accuracy calculation.

## [O\_09] Polyethism in process of food processing within *Odontotermes hainanensis* (Isoptera: Macrotermitinae)

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### Introduction

*Odontotermes hainanensis* is an economically important termite pest that causes serious damage to dikes, dams, residential structures, and historical monuments in Vietnam (Ngo Truong Son 2009; Trinh Van Hanh 2017, 2019; Nguyen Tan Vuong 2007; Nguyen Thi My et al. 2014). Therefore, the development of effective and environmentally control strategies for this species is essential.

Termite bait has advantages not only in terms of efficiency but also in environmental protection. Bait-based termite control using chitin synthesis inhibitors (CSIs) has been widely studied and successfully applied against lower termites, particularly species of the genera *Coptotermes* and *Reticulitermes* (Su et al. 1997; Sajap et al. 2000; Lee 2002; Kubota et al. 2006; Haverty et al. 2010; Su 2014). However, the efficacy of CSI-based baits against higher termites remains limited (Neoh et al. 2011), especially for species belonging to the subfamily Macrotermitinae (Lee et al. 2014). Because bait performance depends on food consumption and subsequent distribution within termite colonies, a clear understanding of foraging, food transfer, and processing behaviors as well as the division of labor in each task is critical. Nevertheless, such information for *O. hainanensis* is still scarce. This study aims to elucidate these processes in *O. hainanensis* colonies, providing a scientific basis for improving bait-based control strategies for this species and fungus-growing termites in general.

### Material and Method

**Caste and worker group classification:** Termites were collected from 31 foraging sites and 57 fungus garden chambers (in which termites were collected immediately in 41 chambers of 18 and termites were collected after one hour opened nest in 16 chambers of four nests) and transported to the laboratory for cooling, sorting, and caste identification, including immatures, soldiers, alates (when present), and workers. Based on head width and body coloration (Nguyen Van Quang 2003), workers of *O. hainanensis* were further classified into four groups: young minor workers (YMiW), old minor workers (OMiW), young major workers (YMaW), and old major workers (OMaW).

**Identification of worker groups involved in fungus garden construction:** Workers collected from fungus chambers were separated by group, and 100 individuals from each group were reared in plastic boxes (50 mm diameter × 30 mm height) containing stained cellulose (0.5% red pigment; 40% moisture) and 0.5 g of fungus garden. Termite activity was observed daily, photographed, and recorded for termite survival, new fungal garden formation (colored fecal pellets), and harvesting behavior (gnawing marks on the substrate). Each treatment was replicated three times and repeated in five independent experiments.

**Assessment of food transfer in field colonies:** Three *O. hainanensis* nests located in a dike were identified based on swarming holes. In each nest, a fungus comb chamber was opened and replaced with 30g of stained cellulose powder, then covered with soil. After one week, nests were dissected to assess food distribution based on the presence of stained fungus combs.

## Results and Discussion

The result in table 1 showed that distinct differences in caste composition among sampling conditions, indicating clear labor division in *O. hainanensis*. Foraging sites were dominated by OMaW (81.94%), confirming their primary role in food collection and transport. In fungus garden chambers sampled immediately, YMaW were most abundant (35.66%), suggesting their key involvement in fungus garden construction. One hour after disturbance, the proportions of soldiers and OMiW increased markedly, while YMiW declined, reflecting rapid recruitment for nest defence and repair.

Table 1. Percentage of each adult termite caste in each sampling condition

Sites	Soldiers	OMaW	YMaW	OMiW	YMiW
Foraging sites	5,87±2,26	81,94±3,66	12,19±2,91		
Fungus garden chambers (collected immediately)	9,17±3,27	18,22±9,97	35,66±6,28	9,69±4,72	24,51±9,19
Fungus garden chambers (after one hour)	35,64±9,91	19,21±6,83	3,96±4,49	38,83±11,71	2,35±1,59

Results on caste-specific roles in fungus garden establishment showed that only YMaW could initiate new fungus gardens. Successful establishment was detected as early as day 3 and reached a stable level of 86.67% from day 7 onward, whereas no new fungus garden was observed in boxes containing other worker groups (Table 2).

Table 2. Percentage of rearing boxes with newly established fungus gardens of each termite worker group over time

Time (days)	OMaW	YMaW	OMiW	YMiW
3	0,00	40,00	0,00	0,00
7	0,00	86,67	0,00	0,00
14	0,00	86,67	0,00	0,00
21	0,00	86,67	0,00	0,00
28	0,00	86,67	0,00	0,00
35	0,00	86,67	0,00	0,00

In addition, daily experimental monitoring results also showed that the fungus cultivation time ranged from 21 to 35 days, and YMaW exhibited the highest survival throughout the experiment, whereas minor workers, particularly YMiW, experienced rapid mortality and did not survive beyond 21 days. These findings demonstrate that YMaW are functionally specialized for fungus garden initiation and maintenance in fungus-growing termite colonies. Temporal changes in fungus garden condition during the experimental period (Figure 1).

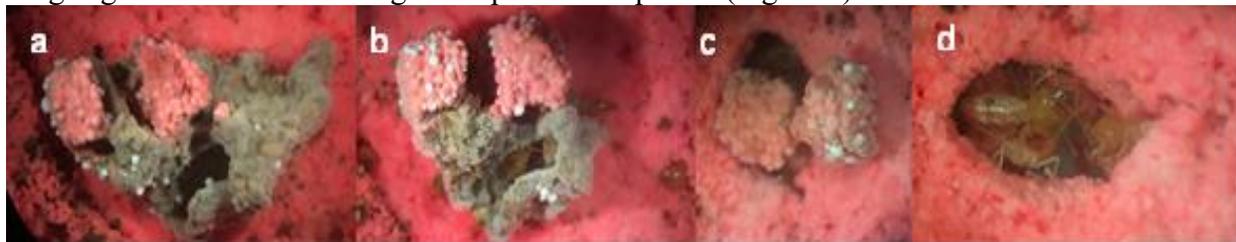


Figure 1. Developmental stages of *O. hainanensis* fungus gardens in laboratory rearing boxes (a-newly established fungus garden, b-fungus garden with nodules; c-old fungus garden, d-fungus garden completely consumed)

Field food-marking experiments showed that food was distributed to most of the fungus garden cavities of the colonies. The proportion of cavities that fungus combs containing marking food reached from 92.1% to 100% in these studied nests.

### Conclusion

This study demonstrates a clear division of labor in *O. hainanensis*, with distinct caste-specific roles in foraging, fungus garden construction, and nest defense. Young major workers are functionally specialized for initiating and maintaining fungus gardens and exhibit the highest survival, whereas old major workers dominate foraging and food transport. Efficient food distribution throughout the colony further supports the feasibility of bait-based control strategies. Together, these findings provide a critical biological foundation for developing effective bait systems for managing fungus-growing termites, particularly *O. hainanensis*.

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## [O\_10] Colony Development Under Stress: Impacts of Forager Loss on Reproductive Performances in Early-Stage Termite Colonies

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### Introduction

The early-stage of termite colonies is a critical stage within the lifetime of a colony, as many events are potential bottlenecks to colony growth. This critical period, starting with colony foundation, first brood rearing by biparental, and full brood rearing by alloparental, is the stage that determines colony survival (Chouvench 2022). In the first two stages, success relies heavily on the resources of the primary reproductive (Chouvench 2019); when entering the alloparental stage, colony success relies heavily on foragers, especially workers. The more workers produced will increase colony survival through increased fecundity and fertility. However, how the reproductive caste in young colonies is affected by forager loss has not been explored. Therefore, in this study we aim to determine the effects of forager loss in early-stage colonies (incipient and immature colonies) of *Coptotermes gestroi* on reproductive output. The assessment of reproductive output is conducted through various metrics, including the total number of individuals, eggs, and the weight of primary reproductive, to observe the difference between treatments.

### Material and Method

Early-stages termite colonies of *C. gestroi* were used in the study, which were raised from one pair of alates in the laboratory for 6 months for incipient colonies and 18 months for immature colonies. Incipient colonies contain  $39.7 \pm 5.1$  workers and  $3.4 \pm 0.5$  soldiers. Immature colonies  $609.0 \pm 49.2$  workers, and  $45.4 \pm 12.3$  soldiers

A total of 20 incipient colonies were used in this study and assigned to four forager-loss treatments: 0% forager removal (no workers or soldiers removed; control), 10% removal (4 workers and 0 soldiers), 25% removal (10 workers and 1 soldier), and 50% removal (20 workers and 2 soldiers). Each treatment was replicated five times. In addition, 20 forager-removal trials were conducted on immature colonies, using the same four treatment levels: 0% removal (no workers or soldiers removed; control), 10% removal (61 workers and 5 soldiers), 25% removal (152 workers and 11 soldiers), and 50% removal (305 workers and 23 soldiers). Foragers were removed using a bait wood method, using radiata pine wood blocks to minimized disturbance to the central nest and allowed forager removal without damaging the core structure of the colony. After removal treatments, all colonies were placed in a room at 28°C and 24h darkness. After 70 days, all colonies were opened, the body weight of the king and queen was measured. The total number of egg, and total number of individuals were counted.

Descriptive statistics were used to show number or weight of individuals, and all results in the main text are presented as mean  $\pm$  standard deviation (Mean  $\pm$  SD). To compare the number or weight across treatments, we performed ANOVA, followed by Tukey's Honest Significant Difference (HSD) post hoc tests where appropriate, using Minitab version 21.4.3.

### Results and Discussion

In incipient colonies the number of eggs drop in loss 50% (table 1), and its shown sign of the burden of brood care, which implying limited egg-laying activity from the queen or eggs cannibalism. In the 10% and 25% forager-loss treatments, the colonies retained a sufficient workforce to maintain functional reverse parental care, which in turn in increased queen fertility. This is reflected in the total number of individuals which both of the treatments have the same number of total individuals. The ability to absorb disturbances that occur is also related to the reserve of nutritional resources owned by queen and king. With sufficient nutrient reserves, primary reproductive can absorb disturbances caused by forager loss and maintain colony fecundity. Based on study, of Chouvench (2019), primary reproductive lose 14.9% of their initial weight, after nine months. If queen and king in foundation colonies have less weight, they do not have enough nutrients to respond to the disturbances. With sufficient nutritional reserves, queen can maintain their fecundity and entering the next oviposition stage earlier.

In immature colonies, queen starts showing early signs of physogastry as it expands ovarian capacity with the addition of functional ovarioles (Raina et al., 2003). The condition of physogastric development of queens can be seen from the weight of queens that differ significantly between the control and treatment. The maximum physogastric development was seen in the control with production of eggs  $386.3 \pm 126.4$  and dropped significantly to  $197.7 \pm 65.4$  in the 10% loss treatment and in contrast, no eggs were found in the 50% loss group (table 1.). Indicating a complete failure of physogastry and reproductive shutdown. These findings confirm that forager loss critically impairs the queen's ability to produce eggs by limiting the physiological development necessary for sustained fecundity.

For physogastry, queens need nitrogen, often transferred from workers and via exuviae (Inagaki et al. 2020; Tong et al. 2023a). Workers, the main foragers, molt centrally (Kakkar et al. 2017) and shed nitrogen-rich exuviae (11.24% N; Tong et al. 2021). When bait wood method forager removal eliminates W2+ workers, it impairs nitrogen recycling. Tong et al. (2023a, 2023b) demonstrated that queens receiving nitrogen from exuviae laid significantly more eggs. Removal of workers individuals in their intermolt period critically reduced egg production. Therefore, forager loss >25% critically limits nitrogen availability, stalling physogastry and leading to colony collapse.

### **Conclusion**

Workers as the largest part of foragers are a key factor in determining the success of colonies in responding to disturbance in the form of forager loss. In incipient colonies the queen responds by entering the next oviposition stage earlier, which allows the colony to recover immediately. In immature colonies losing  $\geq 25\%$  of foragers caused failure in queen fecundity, because queen didn't have enough nutrients intake to enter the next stage of physogastry and leading to colony collapse.

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## [O\_11] Functional Adaptations of Shelter Tubes in Higher Termites (Blattodea: Termitidae)

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### Introduction

Termites are key decomposers in tropical and subtropical ecosystems (Wilson, 1992). Higher termites (Termitidae) comprise over 70% of described termite species and exhibit diverse ecological and behavioral traits (Krishna et al., 2013). Unlike lower termites that rely on gut protozoa, higher termites depend on bacterial and archaeal symbionts for lignocellulose digestion, and some taxa cultivate symbiotic fungi in specialized gardens (Brune, 2014; Darlington, 1982; Jmhasly and Leuthold, 1999). Termites invest heavily in nest construction, including shelter tubes that connect nests to food sources and protect foragers from predators and environmental stressors such as sunlight and rainfall (Lee and Wood, 1971; Chiu et al., 2022). Despite their ecological importance, the adaptive significance of shelter tube construction in tropical higher termites remains understudied.

### Material and Methods

Shelter tubes and termites from six genera (*Odontotermes*, *Microcerotermes*, *Hypotermes*, *Macrotermes*, *Globitermes*, and *Nasutitermes*) were collected in Chiang Mai and Lamphun, Thailand, and identified using morphological keys (Sornnuwat et al., 2004). Shelter tube area density was calculated as mass per surface area. Moisture permeability and water-drop resistance were measured using modified wet cup and water-drop methods, respectively (Kumaran, 1998; McCalla, 1944; Chiu et al., 2022). Water content and organic matter were determined following standard soil analyses, with carbon measured by the Walkley–Black method (Voroney, 2018; Okalebo et al., 2002; Nelson and Sommers, 1996). Data were analyzed using Kruskal–Wallis tests with Tukey-adjusted post hoc comparisons and multiple regression (R Development Core Team, 2013).

### Results and Discussion

Organic matter content (OM%) differed significantly among genera, nesting types, and symbiotic strategies ( $p < 0.0001$ ). *Nasutitermes* showed the highest OM% and water content, while *Hypotermes*, *Odontotermes*, and *Macrotermes* were lower. Arboreal and non-fungus-growing termites constructed OM-rich tubes with greater water retention and higher resistance to raindrop impact. Shelter tubes significantly reduced water loss compared with uncovered controls across all genera ( $p < 0.0001$ ), with water loss reduction primarily influenced by tube thickness, whereas moisture retention and impact resistance were driven by OM%. Thick tubes characterized *Globitermes* and *Macrotermes*, while *Nasutitermes* built thinner but OM-rich tubes. Multiple regression confirmed OM% as the main determinant of moisture regulation and structural resistance, while thickness primarily reduced water loss.

These patterns suggest that higher OM% enhances water retention and mechanical stability by increasing cohesion among incorporated materials such as soil, wood, feces, and saliva (Grassé, 1959; Stoops, 1964; Wood, 1988; Bignell, 2006; Adamu and Aliyu, 2012; Han et al., 2025). Non-

fungus-growing termites showed higher OM%, water content, and impact resistance than fungus-growing termites, reflecting a trade-off in which organic resources are preferentially allocated to fungus gardens in *Odontotermes* and *Macrotermes* (Ndiaye et al., 2004; Rouland-Lefèvre et al., 2006; Li et al., 2017). Shelter tube construction complements physiological traits such as desiccation tolerance, with taxa adopting different architectural strategies according to ecological exposure (Wanthathien et al., 2023). Together, these results demonstrate that termites integrate material composition, structural design, and physiology to cope with environmental stress. Relationships between shelter tube traits and functional properties in six termite genera (50 colonies: *Odontotermes*, *Microcerotermes*, *Hypotermes*, *Macrotermes*, *Globitermes*, and *Nasutitermes*) analyzed using a multiple regression model.

Dependent variable	Independent variable	Slope	F	P-value
Reduction of water loss	Thickness	0.18 ± 0.03	9.124	<0.0001
	OM%	-	-	0.820
Water Drop Resistance	OM%	6.11 ± 0.96	12.66	<0.0001
	Thickness	-	-	0.690
Soil water content of shelter tubes	OM%	0.23 ± 0.04	36.54	<0.0001
Color of shelter tubes	OM%	0.04 ± 0.02	11.89	<0.05

## Conclusion

Termite shelter tubes are flexible, adaptive structures shaped by symbiosis, nesting ecology, and physiology. Organic matter content enhances water retention and resistance to raindrop impact, whereas tube thickness primarily reduces water loss. Arboreal and bacterial-symbiont termites invest in organic-rich tubes, while fungus-growing species compensate lower organic content with thicker or subterranean constructions, revealing a trade-off driven by symbiotic strategy. Desiccation resistance emerges from the integration of physiological tolerance and architectural design. Open-air foraging taxa further indicate that shelter tubes are not universally required, highlighting the evolutionary flexibility of termite survival strategies.

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## [O\_12] Plastic development pathway of reproductive caste of *Prorhinotermes flavus* (Blattodea: Psammotermitidae)

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### Introduction

The proportion of neotenic in *Prorhinotermes flavus* (Bugnion & Popoff) is very high, approximately 2.0–12.9%, and in previous studies, primary kings and queens were absent in the field colonies (Li & Tsai, 1976; Li et al., 2011). These findings indicate that neotenic play a crucial role in the persistence of *P. flavus* colonies. *P. flavus* processes linear developmental pathway, in which both pseudergates and nymphs are able to molt into neotenic, respectively apterous and brachypterous neotenic (Roisin, 1988; Noirot & Pasteels, 1987). In *P. flavus*, the morphology of brachypterous neotenic is variant (Li et al., 2011), suggesting that different types of brachypterous neotenic morphologies might develop from different nymph instars. To clarify the developmental origins of the various types of brachypterous neotenic, laboratory rearing trials were conducted. Additionally, to understand the actual reproductive caste composition in field colonies, we analyzed the caste composition of six field colonies.

### Materials and Methods

To clarify the instar number of the nymphs, both rearing and morphometric analyses were conducted. In the rearing experiment, individual nymphs were maintained with opposite-sex pseudergates and soldiers to ensure that observations could focus on the target nymph. In this trial, 54 replicates from three colonies, hourly photographs were taken to document the molting event. In the morphometric analyses, 94 field-collected nymphs were measured for head width, pronotum width, and wing-pad length following Roonwal (1969) to examine morphological clustering. After confirming the instar number of nymphs, we assessed the reproductive castes that nymphs could molt into by rearing groups composed entirely of nymphs (five males and five females), with three replicates from three colonies. Similarly, pseudergate developmental potential was examined; groups of 20 pseudergates were observed twice weekly to record transitions into neotenic, soldiers, or nymphs. For field castes composition analyses, six colonies from Siangjiao Bay Ecological Reserve, Kenting, Taiwan, were examined. Individuals were identified according to the morphology described by Li et al. (2011), and the reproductive castes were identified based on the rearing results of this study. Reproductive caste composition was then assessed.

### Results and Discussion

Nymphs were confirmed to have a single instar. Nine individuals successfully molted into alates, each after only one molt. During development, compound eyes darkened, wing pads thickened, and bristles formed beneath the epidermis. Nymphs that did not develop into alates either died or regressed into brachypterous pseudergates. Morphometric analyses of nymphs also showed no evidence of multiple instars. Nymphs could directly molt into alates and brachypterous neotenic type I. Depending on the nymph developmental stage, the wing pad length of brachypterous neotenic type I were variable. In addition to directly molting to reproductive castes, nymphs could undergo regressive molts into brachypterous pseudergate, and brachypterous presoldier type I. Apterous and brachypterous pseudergates could molt into apterous neotenic and brachypterous neotenic type II, respectively. Furthermore, apterous and brachypterous pseudergates could molt into apterous presoldier and brachypterous presoldier type II, respectively. In the field colony

castes composition analyses, among colonies that contained neotenics, brachypterous neotenic type II were the most frequent, followed by brachypterous neotenics type I and apterous neotenics. In some colonies, alates were observed, but no primary reproductives were found. Morphometric comparisons showed that apterous neotenics were the smallest, followed by brachypterous neotenics type II, brachypterous neotenics type I, while alates had the largest body dimensions. The similar shapes of the mesonotum and metanotum in apterous neotenics and brachypterous neotenics type II suggest that these forms may have been misidentified in earlier studies. Developmental strategies differed between colony stages: incipient colonies produced more neotenics from apterous pseudergates, whereas mature colonies produced more from nymphs or brachypterous pseudergates. Additionally, even when nymphs were removed from their original colonies and reared under identical conditions, their developmental tendencies remained consistent with their colony of origin.

### **Conclusion**

*Prorhinotermes flavus* exhibits extensive plasticity in reproductive caste development. Both pseudergates and nymphs retain totipotency, resulting in diverse reproductive forms. This study elucidates the plastic developmental pathways of four types of reproductive castes in *P. flavus*.

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## **ORAL LECTURE SESSION S3**

## **TERMITE MANAGEMENT: CHEMICALS**

## [O\_13] KMITL Nano-Oil: Essential Oil Nano-emulsion for Termite Control

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### Introduction

Termites are among the most destructive structural and agricultural pests worldwide, causing substantial economic losses to forestry, orchard systems, and wooden structures. In Thailand, *Microcerotermes* species are widespread wood-feeding termites characterized by cryptic nesting behavior and extensive mud-tube foraging networks, enabling continuous and often unnoticed economic damage to crops, orchard trees, and built structures (Lertlumnaphakul et al., 2022).

Current termite management in Thailand relies predominantly on synthetic insecticides such as fipronil and cypermethrin. Although effective, these chemicals raise increasing concerns related to environmental persistence, non-target toxicity, and the potential development of insecticide resistance (Sanchez-Bayo and Goka, 2014). These limitations have stimulated interest in plant-derived termite control agents, particularly essential oils, which exhibit multi-component insecticidal activity and degrade more rapidly in the environment. Nevertheless, their practical application remains limited by high volatility, low stability, and dose-dependent toxicity, highlighting the need for improved formulations.

Therefore, this study aimed to develop and evaluate essential oil nano-emulsion formulations (KMITL Nano-Oil) with improved stability and termiticidal efficacy, targeting both direct contact and bait-based applications, as a potentially effective and safer alternative for termite management.

### Material and Method

Fourteen plant essential oils previously reported to exhibit insecticidal activity were preliminarily screened against worker termites (*Microcerotermes sp.*) using contact toxicity bioassays under closed-system conditions. Essential oils showing promising termiticidal activity were selected for nano-emulsion formulations. Nano-emulsions were prepared using optimized ratios of surfactant, co-surfactant, and an adhesion enhancer. The physicochemical properties of each formulation, including hydrodynamic particle size, polydispersity index (PDI), and zeta potential, were determined using a NanoPlus Zeta/Nano Particle Analyzer (Micromeritics Instrument Corporation, Japan) according to the manufacturer's instructions.

Three selected formulations, namely CLEO-, CNEO-, and SAEO-Nano-Oil (KMITL Nano-Oil), were evaluated for termiticidal efficacy under closed-system conditions using two bioassay approaches: (1) contact toxicity bioassays, filter papers treated with five concentrations of each nano-emulsion were placed in sealed glass Petri dishes and exposed to worker termites. Mortalities were recorded for up to 48 h to estimate median lethal concentration (LC<sub>50</sub>) and median lethal time (LT<sub>50</sub>) and (2) bait toxicity bioassays, nano-emulsion formulations were incorporated into a cellulose-based carrier at a concentration of 250 ppm, Bait acceptance and termite mortality were assessed after 24 h using sealed acrylic test chambers.

## Results and Discussion

CLEO- and CNEO-Nano-Oil exhibited small particle sizes (<50 nm) with moderate negative zeta potentials, indicating good colloidal stability. In contrast, SAEO-Nano-Oil exhibited a larger particle size (~342 nm) but a low PDI, suggesting a uniform but coarser nano-emulsion system. In contact toxicity bioassays under closed-system conditions, CLEO-Nano-Oil demonstrated the highest acute toxicity, with the lowest LC<sub>50</sub> and the shortest LT<sub>50</sub>. CNEO-Nano-Oil showed moderate contact toxicity, SAEO-Nano-Oil exhibited lower acute contact effects. In bait toxicity bioassays, SAEO-Nano-Oil was the only formulation accepted by termites, resulting in the highest mortality at 24 h (78.3%). Although CLEO- and CNEO- Nano-Oils were not accepted as bait, they still caused moderate mortality, due to vapor-phase or incidental contact exposure within the closed-system. These findings indicate differentiation among the formulations. CLEO- and CNEO-Nano-Oils exhibited strong acute contact toxicity, supporting their potential use as surface sprays or direct contact treatments (Souto et al., 2025). In contrast, SAEO-Nano-Oil demonstrated superior bait acceptance and delayed toxicity, bait-based termite management, where ingestion and non-immediate action are critical for colony-level suppression (Chouvenc, 2025).

Table 1. Physicochemical characteristics and termiticidal performance of KMITL Nano-Oil.

KMITL Nano-Oil Formula	Physicochemical Properties			Termiticidal Activity under Closed-System Conditions			
	Particle size (nm)	PDI	Zeta Potential (mV)	Contact Toxicity Bioassays		Bait Toxicity Bioassay at 24 h	
				LC50 at 24 h	LT50 at 250 ppm	Bait Acceptance	Mortality (%)
CLEO-Nano-Oil	43.5±0.4	0.28±0.01	-13.3±1.1	70.6 ppm	2.08 h	Not accepted	39.0
CNEO-Nano-Oil	41.9±0.3	0.27±0.01	-14.6±0.7	130.5 ppm	9.31 h	Not accepted	45.7
SAEO-Nano-Oil	342.4±1.8	0.08±0.02	-1.38±0.34	332.8 ppm	24.28 h	Accepted	78.3

## Conclusion

KMITL Nano-Oil significantly enhanced termiticidal efficacy and enabled differentiation between contact- and bait- oriented applications. CLEO- and CNEO- Nano-Oils, are suitable for direct-contact termite control, whereas SAEO-Nano-Oil showed bait acceptance and indicating potential for toxic bait development. These results support the integration of essential oil-based nano-emulsions into IPM programs as effective and potentially safer alternatives for termite control.

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## [O\_14] Fluorescence of Metamisalt as a termiticide

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### Introduction

Metamisalt (Dicloromezotiaz), is a novel termiticide recognized for its strong efficacy against subterranean termites. Developed as a soil-applied termiticide by Zen-Noh and its affiliate ZM Crop Protection (ZMCP), it has been being widely developed in some Asian and American countries since its introduction in Japan in 2021. Ensystem and ZMCP presented Metamisalt at the PRTRG conference in 2024. This article provides updated results from ongoing tests conducted since that presentation. In addition to confirming its superior termite control performance through laboratory and field evaluations, we highlight its unique fluorescence capability, which offers new insights into its potential applications in structural pest management.

### Field Efficacy of Metamisalt 6 years after Application in Japan

Under Japanese field conditions, residual biological efficacy was demonstrated for a period of six years following soil application.

### Fluorescence and Chemical Structure

Metamisalt is highly distinctive not only because of its remarkable biological activity against termites, but also from the perspective of physical chemistry. It is an organic compound with a complex and unique framework having a pyridopyrimidine skeleton, and it possesses structural features, which are expanded  $\pi$ -conjugation and rigid structure, that are characteristic of fluorescent molecules.

### Benefit of Fluorescence as Termiticide

A distinguishing feature of Metamisalt is its intrinsic fluorescence under ultraviolet (UV) light, a property absent in its soil metabolites. Unlike the parent compound, Metamisalt's soil metabolites are white, have no fluorescence and are inactive against termites. This fluorescence allows for visual confirmation of the application area and residue status on treated surfaces such as soil, concrete, and wood, and for soil, allows for visual confirmation of the active ingredient content not only on the surface but also in the soil. The intensity of fluorescence correlates with the concentration of the active ingredient, allowing for non-invasive, cost-effective post-treatment monitoring using commercially available blacklights. This innovation eliminates the need for expensive analytical methods and enhances confidence in treatment efficacy.

An additional interesting observation fact is that the compound's transfer effect may occur not only through grooming and trophallaxis but also when other termites contact excreta (feces or vomit) from distressed individuals containing Metamisalt. This mechanism could significantly enhance spread within the colony. The excreta also fluoresce under UV light, indicating that excreta contain effective amount of Metamisalt.

## **Conclusion**

Metamisalt represents a significant advancement in termiticide technology, offering a rare combination of potent insecticidal action, environmental safety, and practical usability. Its unique transfer effect, fluorescent traceability, and robust soil stability position it as a leading candidate for global adoption in termite management. Ongoing development in multiple countries underscores its potential to redefine standards in soil-applied termiticides.

We continue the test to proof the longevity of performance for soil application and expand target species from Japan local to global.

## **Reference**

Y. Baba, T. Hattori et al. 2025. Fluorescent properties of Metamisalt (Dicloromezotiaz), a new termiticide, Abstract for the Annual Meeting of Japan Wood Protection Association.

## [O\_15] Sustainable biobased polyamide for termite proof jacketing solutions

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### Introduction

Termites are ubiquitous insects, and particularly, several termite species are also significant economic pests, attacking in urban area's human made structures. Problems associated with termite attack on underground cables have been recognized for at least 100years. Engineering companies have explored versatile technologies to prevent from termite attacks. However, it is known termites' strong jaws can bite through polymer sheath and chemically attack with corrosive formic acids. Polyamide (nylon)12 jacket is known as termite proof solution since 1960s thanks to its superior hardness compared to other plastics such as PVC or PE, smoothness which prevents termite mandibles from gaining a grip, and superior chemical resistance which resists formic chemical attacks. This polyamide is durable, flexible and chemically stable, and does not contain harmful chemicals such as pesticides which can leech soils and impacts small organism besides termites.

Its termite proof performance has been proven by numerous field tests in several countries against important species such as:

*Copotermes aciniaciformis*

*Copotermes lacteus*

*Coptotermes formosanus*

*Mastotermes darwiniensis*

*Nasulitermes exitosus*

Jacketing materials have to cover evenly wires and have to withstand bending associated with factory process and eventually harsh outdoor exposures under UV and heat without deteriorating smooth hard surface.

Arkema has been producing polyamide 11 and 12 for many decades and supplying to various demanding applications such as automotive, electric, textile, sports goods, medical, 3D printing, and even cosmetic ingredients. Polyamide 11 is unique sustainable bioplastics made from castor oil, which has no nutrition value and do not cause deforestation.

Arkema has redesigned flexible polyamide 11 chemistry enabling to pass AS/NZS 1660.2.4 without compromising physical and chemical resistance properties, performing as good as polyamide 12. In addition, formic acid has been used to confirm chemical stability of polyamide 11 and 12 over PVC polymers.

### Material and Method

#### Testing materials

Many families of ants possess venom which is ancestral traits of chemical defense. Among group of venom in termite, around 50% concentrations are known to be formic acid which is easy to be synthesized by their metabolic pathways. Organic acid such as formic acid could chemically attack and cause degradation of polymers. 50% formic acid solution was used for aging ISO527 1A dumbbells to assess chemical resistance for 30 days with following mechanical tensile and chemical analyses.

Along with commercially available polyamide 12, PE and PVC products for cable jacketing materials, thermally and UV stabilized polyamide 11 has been formulated and its performance was compared against AS/NZS 1660.2.4.

## Results and Discussion

Formulated polyamide 11 performance has been compared with commercially available polyamide 12 following ISO527 tensile, ISO Charpy and AS/NZS 1660.2.4 standards. Formulated flexible polyamide 11 performs as good as commercially available polyamide 12. Some data such as elongation and notched Charpy impact of polyamide 11 shows better performance, which can be explained by more packed  $\alpha$  triclinic cell crystalline structure with formation of hydrogen bond of polyamide 11, whereas polyamide 12 has looser  $g$  monoclinic or pseudo-hexagonal cell without hydrogen bond.

Table 1. Performance comparisons of formulated polyamide 11 and commercially available polyamide12 according to ISO 527, ISO 179 and AS/NZS1660 standards.

		Polyamide 11 plasticized (formulated)	Polyamide 12 plasticized (reference)		
Tensile	Tensile Modulus	470	420	MPa	ISO 527 1A (23degC)
	Stress at break	60	65	MPa	
	Strain at break	350	280	%	
Charpy impact	Unnotched 23degC	no break	no break	kJ/m2	ISO 179 1eU
	unnotched -30degC	no break	no break	kJ/m2	
	Notched 23degC	95	7	kJ/m2	ISO 179 1eA
	Notched -30degC	5	5	kJ/m2	
Carbon black concentration		2.0 ± 0.3	2.0 ± 0.3	%	AS/NZS 1660.2.4
Carbon black dispersion	uniformity of appearance	better than photoA in standard	better than photoA in standard		
	Numerical rating	below 5	below 5		

By formic acid aging, PVC surface became rough, while polyamide 11 or 12 surfaces were intact. Mechanical testing has been carried out to verify formic acid chemical attacks; polyamide 11 and 12 maintained tensile elongation, but PVC showed drop of tensile elongation. Once termite mandibles gain grip at cable sheath, attacked points could become initiation point of cracking with these additional chemical attacks of termites. This experiment has proven chemically stable flexible polyamide 11 and 12, which can be said as one of the crucial factors for termite protection layer in cable sheath.

## Conclusion

Arkema redesigned formulation of flexible polyamide 11 chemistry enabling to pass AS/NZA AS/NZS 1660.2.4. Chemically resistant polyamide performance has been proven by formic acid aging experiments. Field test trials shall be conducted to further verify performance of long chain polyamide 11 and/or 12.

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## [O\_16] Efficacy of Arnica Extract-Based Termiticide from Berkem Biosolutions® in Subterranean Termite Control: A Comprehensive Laboratory and Five-Year Field Evaluation

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### Introduction

Subterranean termites pose significant threats to structural integrity and economic stability. Traditional management has relied heavily on soil barrier treatments using persistent organic pollutants (POPs), but global environmental mandates, such as those by the UNEP (Verma et al., 2018) have accelerated the search for sustainable, bio-pesticide alternatives. Recent research highlights the potential of plant-derived secondary metabolites in termite control (Himmi et al., 2013; Mishra et al., 2021; Souto et al., 2021; Tarmadi et al., 2014).

This study investigates the efficacy of Arnica Biosolution (Berkem Biosolutions®), a water-based formulation incorporating polyphenolic Arnica extract, in both laboratory and field conditions. While laboratory tests provide a controlled environment conducive to establishing cause-and-effect relationships, its artificial settings may not accurately represent real-world scenarios.

### Material and Method

Bio-based termiticide product (Arnica Biosolution)

The evaluated product is a water-based liquid formulation containing polyphenolic plant extracts from Berkem Biosolutions®. The core bioactive component, Arnica extract, is processed using advanced gel technology to ensure precise dosage application and flavonoid stability.

### Laboratory Assessment

Laboratory trials were conducted using a Bottle H test unit. The methodology strictly adhered to the Japan Wood Preservation Association (JWPA) standard, JWPAS-TS-(1) 2018, to evaluate soil-barrier protection against the subterranean termite *Coptotermes gestroi*.

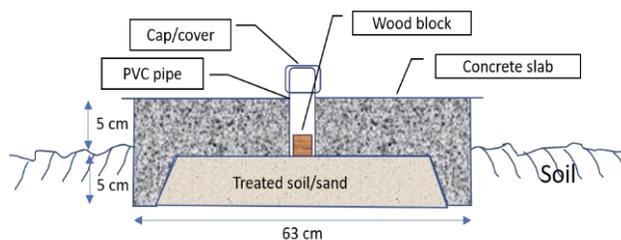


Figure 1. Schematic of the field assessment test unit

### Field Assessment

The field evaluation utilized a simulated test unit designed to mimic real-world soil barrier conditions. The units were installed in January 2021. As shown in Figure 1, the setup included a 5 cm layer of treated soil/sand beneath a concrete slab, with a wood block inside a PVC pipe serving as the monitoring bait. Monitoring was conducted bi-monthly over a five-year

period. Efficacy was determined by the presence or absence of termite penetration through the treated barrier into the PVC pipe.

## Results and Discussion

### Laboratory Assessment

Laboratory assessments provide standardized, cost-effective environments to establish cause-and-effect relationships (Hassan & Morrell, 2021). The results indicated that Arnica extract from Berkem Biosolutions® exhibited: (a) barrier zone integrity, as no termite penetration was observed in any treated soil units, indicating successful soil-barrier formation; (b) lethal effect, as shown by 100% mortality of *C. gestroi* achieved in all treated units; and (c) resistance score, as the product yielded a standardized efficacy score of 1, representing high resistance.

### Field Assessment

The lifespan of soil barrier chemical products against termites varies depending on product quality and application conditions (Borchers & Pieler, 2010). The effective termiticide should be (1) toxic or repellent; (2) applied as a continuous barrier; and (3) maintain efficacy for at least five years, provided the soil barrier remains undisturbed (Oi, 2022). Professional termite management sources indicate that high-quality chemical termite barriers are designed to last up to a maximum of 8 to 10 years.

The five-year field evaluation of Arnica extract from Berkem Biosolutions® demonstrated high resistance and protection against subterranean termites, as no termite penetration was observed in any treated soil test units during four years of observation, indicating effective soil-barrier protection. In the control units, termites fully penetrated the untreated soil and attacked the wood bait within the first month of observation; the wood bait was regularly replaced throughout the observation period. Various subterranean termite species were observed surrounding the testing area, including *Coptotermes* sp., *Macrotermes gilvus*, *Microtermes* sp., and *Odontotermes* sp.

### Conclusion

The Arnica extract-based termiticide from Berkem Biosolutions® demonstrates high laboratory efficacy and long-term field durability. Its ability to provide a complete soil barrier for five years against multiple termite species confirms it as a high-performance, sustainable alternative to conventional chemical treatments.

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## [O\_17] 2-Phenoxyethanol Directs Subterranean Termite Soil Foraging

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### Introduction

The chemical, 2-phenoxyethanol (2-PE) at ~0.08% in water, is an artificial, non-pheromone trailing mimic of *Coptotermes formosanus* Shiraki (Chen et al. 1998, Fei and Henderson 2005, Fei et al. 2005a, Fei et al 2005b) and *Reticulitermes flavipes* (Kollar) (Prescott et al 2021). The 2-PE has been used extensively in the consumer market as an additive to pen ink, cosmetics, and food (“2-phenoxyethanol Uses, Dosage, Side Effects, FAQ” 2021). EPA also ruled that 2-PE used for subterranean termite monitoring and detection is not an insecticide regulated by FIFRA (EPA determination letter 2024). Practical application of 2-PE when applied to the soil surface for termite detection and monitoring is relatively unknown. The objectives of this study were to determine whether 2-PE applied to the soil surface can: 1) connect and direct termites to termite stations surrounding a structure, and 2) detect termites in tree infestations.

### Material and Method

A large condominium complex in Ft. Myers, FL USA was selected by the Ft. Myers Pest Control company after Formosan termites swarmed in one building in late April 2024. For the study, they installed 465 Sentricon stations at ten buildings in May 2024. There were 224 Sentricon stations at five buildings connected with 2-PE soil surface liquid treatments. The 2-PE was diluted to 0.1% and agitated to completely dissolve in water. The water solution was applied to soil surface as a 5-10 cm-wide band using a backpack sprayer. Untreated control building numbers 2, 4, 6, 8 (previous swarms), and 10 had 241 Sentricon stations not treated with 2-PE. Stations were inspected 9 months after treatment for termite activity.

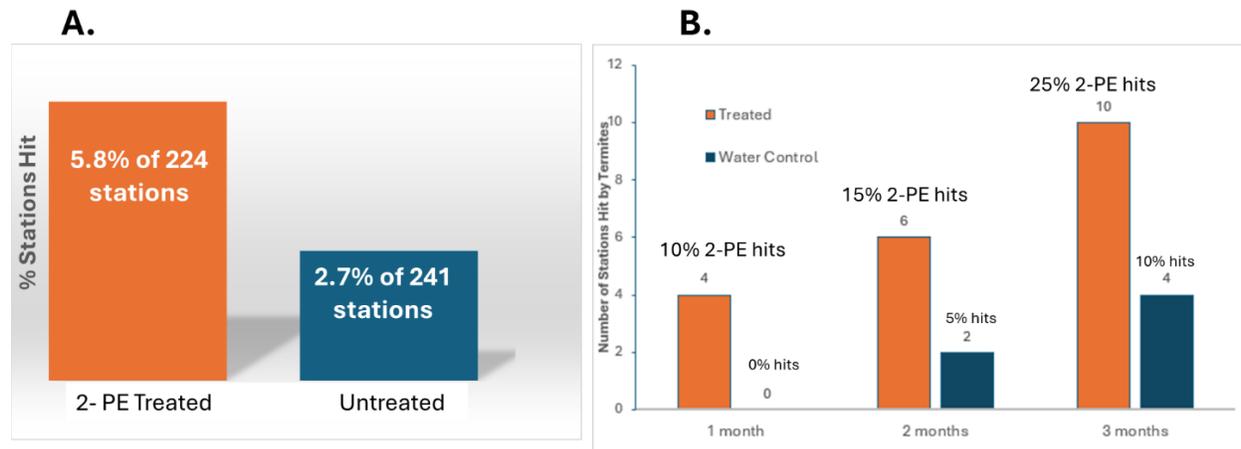
In Jacksonville, FL USA, 20 Formosan termite infested trees were selected for the study. The trees were live oak (*Quercus virginiana*) and southern magnolia (*Magnolia grandiflora*). There were 4 pop-up termite monitors installed in quadrants 1.5 m from the base of each tree. The 2-PE was diluted to 0.1% and agitated to completely dissolve in water. The 2-PE water solution was applied to the soil surface as a 5-10 cm-wide band from the base of the tree to each station and continued in a straight line to 3 m out. A second 3 m band was sprayed at a 90-degree angle to the first line of treatment to medially intersect with the station. For the study, 10 trees were treated with 2-PE, and 10 trees were water treated. Stations were monitored for pop-up station activation monthly for 3 months. The spring-loaded monitor released when cellulose was consumed, and stations were opened to visually confirm termite activity. For both studies, the number of stations with termite activity was counted, and percentage of stations with termites was calculated for each treatment (2-PE or untreated control).

### Results and Discussion

The Ft. Myers FL study determined that 2-PE treatments increased Formosan termite detection by leading termites to termite bait stations faster. A soil surface treatment of 0.1% 2-PE resulted in 5.8% of 224 Sentricon stations having termite activity at 9 months after treatment, compared with 2.7% of 241 untreated stations having termites (Figure 1A). The technical director for the pest control company saw the results of the test and said “I am planning on applying [2-PE] to all my new and renewal termite treatments.”

The 2-PE treatments in Jacksonville, FL led termites from infested trees to popup stations and resulted in 10% activity in stations within 1 month after treatment compared with no activity in the water-treated controls. At 2 and 3 months after treatment, 2-PE treated stations had 15% and 25% activity respectively, compared with 5% and 10% activity.

Figure 1. 2-Phenoxyethanol Directs Subterranean Termite Soil Foraging to Stations: A. Ft. Myers study at condominium complex with Formosan termite activity. B. Jacksonville study at termite-infested trees with mixed Eastern subterranean and Formosan termite activity.



## Conclusion

This study determined that 2-PE applied to the soil surface: 1) connected and directed termites to termite stations surrounding a structure, and 2) detected termites in tree infestations.

## Acknowledgements

We thank Scott Kight of the Ft Myers Pest Control Company for cooperating with the study and applying the treatments. We also thank The Cooperative Extension Office in Duval County Florida, USA and Lindsey Pest Control Company for cooperating with the study and applying the treatments.

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## **ORAL LECTURE SESSION S4**

### **TERMITE MANAGEMENT: STRATEGY AND POLICY**

## [O\_18] Characteristics of termite damage to historical monuments in Ha Nam (currently part of Ninh Binh Province) and proposed control solutions

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### Introduction

Termites are not only pests of crops and hydraulic structures but also major agents of damage to buildings, particularly wooden architectural structures. The global economic loss caused by termites is estimated at approximately 40 billion USD annually (Rust & Su, 2012). In the United States alone, annual expenditures for termite control and building repairs reach around 1.5 billion USD, while in China, in the central region of Sichuan Province, the cost of controlling subterranean termites and mitigating damage amounts to approximately 3 million USD per year (Rawat, 2004). In Southeast Asia, termites represent a significant economic burden, with total estimated losses exceeding 1 billion USD per year across the region (Lee & Lee, 2025). However, in Vietnam, there is still no comprehensive assessment of termite-related damage to architectural structures in general or to cultural heritage sites.

Ha Nam (currently part of Ninh Binh Province), located about 60 km from Hanoi, is an area with a long history of settlement and development, hosting 1,888 historical and cultural monuments, of which 237 are officially recognized, including 2 national special monuments, 95 national monuments, and 140 provincial monuments. Most of these sites are temples, communal houses, and pagodas, with predominantly wooden structures; many have long histories, large-scale architecture, and outstanding artistic value, featuring distinctive and exemplary carvings (Ha Nam Department of Culture, Sports and Tourism, 2024). These monuments hold not only historical, cultural, and architectural significance but also play an important role in the spiritual life of local communities. However, many of these sites are currently facing the risk of deterioration due to multiple damaging factors, among which termites represent a major threat.

In this context, the present study focuses on identifying the main termite pest species, analyzing the causes of infestation, and proposing an integrated management strategy for effective termite control tailored to the characteristics of wooden architectural heritage in Vietnam.

### Material and Method

Survey was conducted in 36 rylics in Ha Nam area, Ninh Binh province, Vietnam from September 2024 to April 2025, using the termite collection method of Nguyen Duc Kham (1971), and the termite names were identified based on document of Nguyen Duc Kham et al. (2007).

The proposed solution is based on the biological characteristics of the pests and the characteristics of the historical monument.

### Results and Discussion

A total of 36 nationally recognized heritage structures in the study area were surveyed to assess termite infestations. Among them, 23 structures (63.9%) were found to be affected by three termite species: *Cryptotermes domesticus*, *Coptotermes gestroi*, and *Odontotermes hainanensis*. *Coptotermes gestroi* was detected in 21 structures, *O. hainanensis* in 10 structures, and *C. domesticus* in 7 structures, with 3 structures simultaneously affected by all 3 species. Although all surveyed sites had previously undergone termite control measures, only 13 structures showed no

current termite activity, nine of which were recently restored and treated within the past 1–3 years. Control methods primarily included manual approaches (e.g., removing termite galleries, applying lime, pouring oil) and chemical treatments (e.g., spraying, soil treatment). Ineffective control was attributed to the inability to distinguish termite groups, improper application of methods, and insufficient monitoring.

The three termite species exhibited distinct nesting and foraging behaviors. *C. domesticus* infests and nests entirely within wood, including columns, door frames, and furniture. Alates swarm in the evening (6.30–8.00pm) during dry, hot days from mid-April to late July, typically in small numbers. *C. gestroi* nests both underground and within structural or surrounding trees, with a wide foraging range affecting columns, beams, roofs, door frames, altars, and nearby vegetation. Alate flights occur in hot afternoons prior to rainfall in April–May, with 1–3 swarming events per colony, ranging from a few individuals to thousands. *O. hainanensis* constructs subterranean nests with one main chamber and multiple satellite chambers, primarily feeding on fungal gardens, and attacks floors, walls, columns, and structural timber. Alates swarm after rainfall between March and April (Trinh Van Hanh, 2008).

Most surveyed structures in Ha Nam feature the northern Vietnamese communal house (Đình in Vietnamese) architectural style, with symmetrical layouts along a central axis, including ponds, ceremonial gates, main halls, rear halls, and side corridors (Vu Thi Ngoc Anh, 2020). Building materials are predominantly wood (50–90%), forming main structural components such as columns, beams, roof systems, doors, and ritual furniture, supplemented with stone (column bases, thresholds) and brick walls, while courtyards are paved with red tiles. Termite infestations occur through pre-existing colonies, external introductions, alate flights, or foraging from surrounding areas, depending on species.

Based on structural characteristics and observed infestation patterns, an integrated termite management strategy is proposed:

- Survey and identification of termite species and activity locations within and around the structures.
- Control of active colonies, both inside structures (pre-existing nests) and in surrounding trees or adjacent sites, applying species-specific methods. For structures affected by all three species, priority is given to controlling *C. gestroi* and *O. hainanensis* before *C. domesticus*. Recommended methods include:

#### **Baiting for subterranean *C. gestroi*.**

Localized treatment for large, non-removable structural components affected by *C. domesticus* or *O. hainanensis*.

Replacement of irreparably damaged components for all species.

☐ Prevention and monitoring, including:

Soil treatment around building foundations.

Installation of light traps for alate capture in surrounding areas.

Establishment of monitoring stations to detect early termite activity and enable timely intervention.

#### **Conclusion**

A total of 23 heritage structures (63.9% of the surveyed sites) were found to be infested by three termite species: *Cryptotermes domesticus*, *Cryptotermes gestroi*, and *Odontotermes hainanensis*.

The proposed management strategy comprises three main steps: (1) surveying and identifying termite activity and nests, if present; (2) controlling active colonies using species-specific methods, including baiting for *Coptotermes* and localized treatment for drywood termites and fungus-growing termites; and (3) implementing preventive measures and regular monitoring to detect and manage termite activity over time.

### **Acknowledgement**

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## [O\_19] Termite damage and management in Korean wooden architectural heritage: a 20-year review and future perspectives

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### Introduction

Numerous wooden architectural heritage sites in the Republic of Korea (South Korea) are currently threatened by termite infestation. Termite activity not only compromises the authenticity of these structures but also reduces their structural stability, making monitoring and control essential for conservation. A recent survey revealed that termite infestations were present in 51% of nationally designated wooden architectural heritage sites (Kim and Chung, 2022a). This study reviews past termite management practices for Korea's wooden architectural heritage and discusses eco-friendly and sustainable approaches for the future.

### Material and Method

To assess the current status and trends, we analyzed the climatic characteristics of Korea, the distribution of termite species, and 216 pest control project reports conducted over the past decade (2013–2023). Based on this comprehensive analysis, we discussed future directions for effective termite management in heritage sites.

### Results and Discussion

#### 1. Climatic Characteristics and Termite Species Distribution in Korea

The Republic of Korea is located on the eastern edge of the Eurasian continent in East Asia. Its climate is characterized by cold, dry winters and hot, rainy summers due to both continental and oceanic influences. Climatological records spanning 1990–2020 indicate that South Korea has a mean annual temperature of 12.5°C and annual precipitation of 1,306 mm. The mean temperature in January, a primary limiting factor for termite distribution, is –0.9°C, though it varies regionally from –6.9°C to 3.6°C. Due to these comparatively low winter temperatures, termite survival in South Korea has historically been restricted to a limited number of cold-tolerant species.

To date, four termite species (*Reticulitermes speratus*, *R. kanmonensis*, *Glyptotermes nakajimai*, and *Incisitermes minor*) have been recorded in Korea (Becker, 1969; Lee et al., 2023; Lee et al., 2024a; Lee et al., 2015; Shim et al., 2021). Among these, the subterranean termite *Reticulitermes speratus* is the dominant species, accounting for the vast majority of damage to wooden heritage (Kim and Chung, 2022b). Many of these heritage sites are situated in forested environments where the risk of termite infestation is persistently high.

Furthermore, global trade and climate change have exacerbated this threat. Over the past 100 years, the mean annual temperature in Korea has increased by 1.5°C, and the mean January temperature by 2.1°C; consequently, it is estimated that the period of termite activity has lengthened (Kim et al., 2023). The introduction of invasive species is a growing concern, highlighted by the discovery of established populations of the Western drywood termite, *Incisitermes minor*, in 2023 (Lee et al., 2024b). There is also increasing concern over the potential introduction of other highly destructive species, such as *Coptotermes formosanus*, facilitated by rising winter temperatures (Lee et al., 2021).

## 2. Current Termite Management Strategies and Limitations

Current management strategies for wooden cultural heritage primarily include the installation of in-ground bait stations and the application of liquid termiticides to the surrounding soil. Soil treatment with liquid termiticides requires the continuous reuse of large quantities of chemicals (4-5 liters per meter) at intervals of approximately 3-5 years. Therefore, it is necessary to reduce the reliance on liquid termiticides and transition towards baiting systems as the primary control method. Historically, bait systems utilizing either fipronil or Chitin Synthesis Inhibitors (CSIs) as active ingredients have been used concurrently in Korea (Kim et al., in press). However, since non-repellent insecticides like fipronil fail to achieve complete colony elimination (Chouvenc, 2018; 2024), a shift towards CSI-based baits is essential for future management. Furthermore, conventional in-ground termite baits often have a significant latency period before termites intercept them, during which additional damage may occur to wooden cultural assets.

### Conclusion

Future strategies must prioritize effective and environmentally friendly methods to prevent damage. Looking forward, an Area-Wide Management (AWM) approach that integrates heritage structures with their surrounding wooden structures and environment is crucial for effective, long-term prevention. From a technical perspective, future strategies should involve the use of high-durability, long-lasting in-ground baits combined with the rapid deployment of above-ground baits upon the detection of indoor termite activity.

### Acknowledgement

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## [O\_20] Area-Wide Evaluation of Bait Density and Cost-Effectiveness in the Elimination of the Formosan Subterranean Termite (Blattodea: Heterotermitidae)

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### Introduction

The Formosan subterranean termite (FST, *Coptotermes formosanus* Shiraki) is one of the world's most destructive invasive pests, resulting in huge economic losses annually (Rust and Su 2012, Bradshaw et al. 2016). Termite baiting with chitin synthesis inhibitor (CSI) baits are effective and environmentally sustainable on subterranean termite control, and has successfully suppressed subterranean termite populations in large urban areas across multiple countries. Although areawide termite baiting can create a long-period termite-free areas, these projects require substantial initial investment, long time on return and municipal involvement. Subterranean termites have repeatedly damaged underground power cables in Taiwan's science parks, causing power outages and substantial economic losses. Areawide termite control using baiting systems provides a cost-effective strategy to establish long-term termite-free zones across entire science parks. Although cost-benefit analyses have facilitated the implementation of agricultural pest management, economic evaluations of areawide termite control remain rare. The bait stations constitute the largest cost component in termite baiting, reducing their cost could substantially lower economic barriers to implementing areawide termite management. Increasing bait-station density beyond effective spacing provides little additional benefit while greatly increasing potential costs (Gazdick et al. 2025). In this study, we conducted a two-year baiting program in two industrial parks in Taiwan. Based on termite colony distribution and territory size, we simulated bait station spacing to evaluate the cost-effectiveness of the respective baiting programs in the two parks.

### Material and Method

Six survey plots with records of termite damage were established in the Central Taiwan Science Park (3 plots) and Hsinchu Science Park (3 plots), and the area of each plot was 1 to 2 ha. The wood stakes as inground bait stations were set up in 5 m interval spacing in the softscape area and termite activity were monitored monthly since March 2023. The alates in the plots were also monitored using sticky traps. The colony of FST were identified using microsatellites, and were eliminated with in-ground Recruit HD bait stations. On the basis of the practical management process, we simulated the scenario of different bait-station spacing scenarios. We assessed the cost and benefit of termite baiting in the science parks and trade-offs of different simulated bait-station spacing scenarios.

### Results and Discussion

Ten FST colonies were identified across both science parks, with five colonies in each park. Colony density averaged  $0.77 \pm 0.45$  colonies ha in the Central Taiwan Science Park and  $1.08 \pm 0.67$  colonies ha in the Hsinchu Science Park. Mean colony territory size was the  $97.5 \pm 76.5$  m<sup>2</sup> in the Central Taiwan Science Park and  $943.3 \pm 1850.7$  m<sup>2</sup> in the Hsinchu Science Park. Two new colonies were intercepted elimination of the original colonies, of which one was baited and eliminated, while the other was not treated due to program termination. Overall, 11 colonies were

baited and eliminated within 1 to 4 months after bait contact, with an average elimination time of  $1.82 \pm 1.25$  months and a mean bait consumption of  $164.3 \pm 68.6$  g per colony. Alate captures did not decrease in the Central Taiwan Science Park after baiting, whereas they declined markedly in the Hsinchu Science Park. Expected number of bait station encountered per colony declined as bait-station spacing increased in both science parks, leading to reduce the probability of colony elimination. In the Central Taiwan Science Park, all colonies were eliminable when the bait station spacing was less than 8 m, whereas less than 12 m spacing of bait station in the Hsinchu Science Park. These increasing spacings also decrease total control costs. The minimalized total cost within 10 years was estimated at NT\$64.97 million for the Central Taiwan Science Park and NT\$68.43 million for the Hsinchu Science Park while all colonies were eliminable. The potential annual losses of termite-caused power outages were estimated by using the daily revenues of the science parks, which is approximately NT\$1.5 billion and NT\$6.08 billion in the Central Taiwan Science Park and the Hsinchu Science Park, respectively. Compared with these losses, the cost of areawide termite control is minimal, clearly satisfying the condition that potential damage far exceeds control costs.

### **Conclusion**

By integrating field experiments with simulations of different bait-spacing scenarios, we provide a cost and benefit analysis of areawide termite management in the science parks and the evaluate the trade-off of maximize colony elimination while minimizing overall control costs. We find that the economic benefits of reducing termite damage in science parks far outweigh the costs of implementing area-wide termite management. This study demonstrates that area-wide termite baiting is both scientifically effective and economically justified for controlling FST in large industrial landscapes.

### **Acknowledgement**

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## [O\_21] Application of Termite Monitoring System Based on DEMINL Technology in Dam Termite Control

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### Introduction

Termites pose a significant biological threat to the safety of water conservancy projects. By constructing nests and intricate tunnels within dams, they create concealed pathways that traverse the embankments. This activity readily triggers seepage, piping, landslides, and even dam failures, constituting a major hazard to the safety of reservoirs, dams, levees, and other water conservancy structures (Qi 2025). Over 80% of reservoirs and dams in southern China suffer varying degrees of termite infestation. Traditional control methods (such as chemical eradication and baiting) suffer from environmental pollution and lack dynamic monitoring mechanisms, resulting in low efficiency and high costs. The advancement of intelligent monitoring technology offers novel solutions to the aforementioned challenges, though it has also given rise to new complications. For instance, loop-based technologies (such as carbon loops) rely on circuit continuity detection, yielding a false alarm rate as high as 52.9% in humid environments; non-loop technologies (such as visual AI) are constrained by image recognition accuracy and environmental interference.

To solve existing issues, we have conducted research on applying DEKAN electromagnetic induction non-loop (abbreviated as DEMINL) technology-based termite monitoring and early warning systems for dam protection. The DEMINIL technology is a termite monitoring technique that employs magnetic induction to detect the presence of termites by measuring magnetic field variations between the sensor and the target object (Sheng 2023). When the pine bait is consumed by termites, its embedded permanent magnet shifts position. The magnetic induction sensor atop the bait detects this magnetic flux change, triggering an alarm indicating termite presence. This non-contact magnetic field detection principle offers potential solutions to challenges facing monitoring technologies, such as high false alarm rates, short operational lifespans, and poor environmental adaptability.

### Material and Method

#### 1. Intelligent Termite Monitoring Device

This intelligent monitoring device typically comprises an equipment housing, a bait-triggering module, and an information collection module (Fang 2023). The bait-triggering module consists of wood pieces and an information trigger block. The information trigger block is composed of wood, a magnetic bar, and spherical particles. When termites gnaw through the information trigger block, the internal spherical particles scatter from the gnawed trigger block holes, causing the magnetic bar to slide downward. This block shift alters the magnetic field detected by the information collection module, triggering an alarm. This signal is then transmitted to the monitoring system via Internet.

#### 2. Intelligent Termite Monitoring and Early Warning System

The Intelligent Termite Monitoring and Early Warning System comprises monitoring devices, data transmission and storage modules, and a central processing and early warning module. Monitoring devices are typically deployed on reservoir dam slopes and areas with frequent termite activity. The data transmission and storage module collects and stores data such as magnetic field signals and voltage signals emitted by monitoring equipment, transmitting it via IoT technologies including LoRa IoT and Cat-1. The central processing and early warning system, serving as the terminal core of the entire intelligent monitoring system, primarily receives and converts signal data. It displays the alarm status of each monitoring point via a graphical user interface.

### 3. Experimental Design and Overview of Study Areas

The experimental areas comprise multiple representative reservoirs across China. The intelligent monitoring and early warning system based on DEMINL technology was deployed at:

- Siming Lake Reservoir (Yuyao City, Zhejiang Province);
- Shaheji Reservoir (Chuzhou City, Anhui Province);
- Zhijiang Crater Reservoir (Yichang City, Hubei Province).

The intelligent termite monitoring and early warning system based on carbon cycle technology was deployed at Shitaiyi Reservoir, Tieluchong Reservoir, and Yaojiazha Reservoir in Hubei Province.

The visualization monitoring and early warning system was deployed at Zhongjiacha Reservoir in Hubei Province.

The termite monitoring equipment is deployed at intervals of 10 meters by 10 meters (with 5 meters by 5 meters spacing at the junction between the dam body and the mountain slope), with adjacent monitoring points arranged in an alternating pattern. This layout ensures comprehensive and representative monitoring coverage. Upon completion of all equipment deployment, the system enters routine monitoring mode, continuously collecting data on termite activity.

### 4. Data Collection and Analysis Methods

To validate the system's accuracy in detecting termite feeding activity, within three days of receiving an infestation alert, we dispatch specialists to verify the status of monitoring rods and signs of termite activity on-site. Field verification results are cross-referenced with alarm records from the monitoring management platform, with system accuracy assessed via the positive signal accuracy rate (ARP) (Su, 2002).

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

TP (true positive), i.e., alarm signal (red spot) and presence of termites or wood pieces attacked by termites;

FP (false positive), i.e., alarm signal (red spot) and absence of termites.

## Results and Discussion

### 1. Alarm Accuracy Rate

The DEMINIL technology utilizes the displacement of permanent magnets triggered by termite feeding activity to activate Hall sensors, thereby enabling direct, non-contact capture of biological signals. This mechanism ensures the system responds exclusively to biological activity such as termites, significantly enhancing alarm accuracy. Calculated from the date of installation, over a three-year operational period: - Siming Lake Reservoir recorded 95 cumulative alarms, achieving an alarm accuracy rate of 95.79%; - Shaheji Reservoir received 73 cumulative alarms over three years, with an alarm accuracy rate of 94.52%; - Zhijiang Crater Reservoir reported 146 data points, demonstrating an alarm accuracy rate as high as 99.32%. The average alarm accuracy rate across the three reservoirs was approximately 96%. In contrast, carbon loop technology, which relies on the mechanical switching of physical circuits, suffers from electrochemical corrosion of carbon

materials in humid soil environments. Its maximum six-month alarm accuracy rate was only 66.67%, with an average alarm accuracy rate across the three reservoirs of 48% (Table 1).

Visualization AI detection employs artificial intelligence image recognition technology, with its termite identification accuracy influenced by factors such as the photographic environment, sampling interval (typically 1-2 hours per session), and algorithm precision. For instance, during rainy seasons like spring and summer when soil moisture significantly increases, camera lenses are prone to vapor interference, resulting in blurred captured images. Without timely manual intervention, the system's monitoring efficacy may be compromised.

## 2. Service Life

The core sensor of DEMINIL technology employs IP68-rated encapsulation, exhibiting sensitivity degradation of less than 3% across temperatures ranging from  $-30^{\circ}\text{C}$  to  $70^{\circ}\text{C}$ . During its five-year operational period at Siming Lake Reservoir, the failure rate remained at just 1.5%. In contrast, carbon loop technology relies on an electrochemical reaction triggered during each detection cycle, revealing significant limitations under identical environmental conditions with a service life spanning approximately six to twelve months.

## 3. Cost-Effectiveness

Although the initial cost per unit of DEMINIL technology exceeds that of carbon loop systems, its full lifecycle maintenance costs over five years amount to merely one-third of carbon loop systems. Taking statistical data from 40 reservoirs as an example, carbon loop systems incur average annual maintenance expenses of 185,000 CNY, primarily for circuit replacement and false alarm troubleshooting. The DEMINIL system, through remote diagnostics and modular design, maintains average annual maintenance costs at 82,300 CNY, exhibiting diminishing marginal costs as deployment scales expand. Visual monitoring requires high-definition cameras and computational support, with initial per-unit investment exceeding 3,000 CNY. Additionally, data transmission incurs annual traffic costs increasing by 42,000 CNY, resulting in persistently high overall expenses.

## Conclusion

The termite monitoring and early warning system based on DEMINIL technology demonstrates superior alarm accuracy, service life, and cost-effectiveness compared to monitoring methods such as carbon loop detection and visual inspection. It enables real-time detection of termite activity and precise early warning, providing critical technological support for establishing a proactive, data-driven modern termite control system for embankments.

Table 1. Operational Data of the Intelligent Termite Monitoring System at Three Reservoirs

Reservoir Name	Number of Monitoring Devices (sets)	Project Implementation Date	Number of Devices Receiving Alarms	Number of Devices Detecting Termites	Alarm Accuracy Rate (%)	Mean $\pm$ Standard Deviation
Siming Lake Reservoir	325	December 2019	95	91	95.79%	96.54% $\pm$ 2.49%
Shaheji	310	October 2020	73	69	94.52%	

Reservoir Name	Number of Monitoring Devices (sets)	Project Implementation Date	Number of Devices Receiving Alarms	Number of Devices Detecting Termites	Alarm Accuracy Rate (%)	Mean $\pm$ Standard Deviation
Reservoir						
Huoshankou Reservoir	165	April 2022	147	146	99.32%	
Shitaiyi Reservoir	43	January 2025	5	3	37.50%	
Tieluchong Reservoir	43	January 2025	7	5	41.67%	48.61% $\pm$ 15.77%
Yaojiazha Reservoir	68	January 2025	2	4	66.67%	

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## **ORAL LECTURE SESSION S5**

## **ECOLOGY OF TERMITOPHAGUS MAMMALS**

## [O\_22] Foraging Ecology of Juvenile Chinese Pangolins (*Manis pentadactyla*)

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### Introduction

The Critically Endangered Chinese pangolin (*Manis pentadactyla*) is distributed across the low-elevation mountainous regions of Taiwan (Chao, 2020). This species is an obligate myrmecophagous and termitophagous mammal (Sun et al., 2025). The pangolin's elusive behavior results in a scarcity of data and difficulties in conducting research on its life history and growth information for wild populations (Gaubert & Antunes, 2005; Irshad et al., 2016), which further impacts its ex-situ conservation and captive management (Hua et al., 2015). Characterizing the dietary composition of wild populations is essential for the successful design and implementation of endangered species conservation programs, such as those for the Chinese pangolin (Redford, 1987; Challender, et al., 2014). In total, 4 termite species (comprising 2 families and 4 genera) and 58 ant species (representing 5 families and 25 genera) were identified from the fecal samples of adult Chinese pangolins (Sun et al., 2025). The Subterranean Termite, *Odontotermes formosanus*, is the sole fungus-growing species of the Macrotermitinae in Taiwan, typically distributed across the island at elevations below 1,200 meters (Chiu et al., 2010). Furthermore, *O. formosanus* represents a critical prey item for the Chinese pangolin, constituting approximately 40% of the adult pangolin's total consumed biomass (Sun, 2020; Sun et al., 2025). Additionally, the alate caste of *O. formosanus* comprises over 50% of the prey biomass consumed during April and June (Sun et al., 2020).

Generally, young individuals in captive or rescue settings exhibit low survival rates, often attributed to stress or complications associated with the weaning process (i.e., the transition from a liquid to a solid diet such as termites and ants) (Sun et al., 2019; Yang et al., 2007). However, a significant gap exists in the current literature regarding dietary research specifically focused on juvenile Chinese pangolins. Consequently, investigating the feeding ecology of juvenile pangolins is imperative for

improving their survival rates in captive or rescue environments and for the effective development of conservation programs. This study analyzed nine fecal samples collected from juvenile pangolins to calculate and estimate (1) the species composition and (2) the biomass percentage of the consumed ants and termites. These results are anticipated to provide crucial reference data on the appropriate diet composition for improving future captive care and orphan rearing protocols for the Chinese pangolin.

### Materials and Methods

A total of nine fecal samples were collected from juvenile pangolins at wildlife rescue centers in Taiwan over the period from June 2011 to July 2024. Juvenile pangolins were defined as individuals weighing less than 1 kg, typically before weaning or achieving independence (i.e., less than six months old) (Sun et al., 2024). The fecal analysis methodology followed the protocol outlined by Sun et al. (2020). Each sample was oven-dried at 60°C for 24 hours. Subsequently, fecal filtering techniques and recovery rates were employed to obtain and quantify the prey items consumed, following the procedures established by Sun et al. (2019, 2010). Ant counts were determined by the number of head capsules, whereas termite counts were based on the number of

mandibles. Species and caste identification and quantification were performed visually with reference to Sun et al. (2025). The retention rates of ant and termite remain in the pangolin feces after digestion were applied to correct the estimated number of consumed prey individuals, based on the methodology of Sun et al. (2020). Prey biomass estimation was caste-specific. For ant taxa, biomass was determined using the method outlined by Kaspari and Weiser (1999). The dietary biomass of termites was estimated using measurements from wild-collected major workers and alates of *O. formosanus*. Biomass calculations for *Nasutitermes parvonasutus* utilized the head width index (Dahlsjö et al., 2015).

### Results and Discussion

In total, 26 ant species and 2 termite species were identified and quantified across the collected fecal samples. The identified ant species were primarily concentrated in the subfamily Myrmicinae (12 species), followed by Formicinae (10 species). The remaining taxa comprised Dolichoderinae (2 species), Aenictinae (1 species), and Ponerinae (1 species). The two identified termite species, *O. formosanus* and *Nasutitermes parvonasutus*, both belonged to the family Termitidae. On average, each fecal sample contained  $1.1 \pm 0.3$  termite species (ranging from 1 to 2) and  $6 \pm 2.9$  ant species (ranging from 1 to 10). The Formosan Subterranean Termite (*O. formosanus*) exhibited the maximum occurrence frequency (100%) across all samples. The yellow crazy ant (*Anoplolepis gracilipes*) was the second most frequent (77.78%), followed by the black crazy ant (*Paratrechina longicornis*) at third (66.67%). Significantly, both of these ant species are recognized as invasive species in Taiwan.

In terms of consumed biomass, *O. formosanus* represented the greatest proportion, accounting for 52.25% of the average total ingested biomass across all nine samples, followed by the two invasive ant species, which collectively accounted for 25.6% (Fig. 1A). Within *O. formosanus*, the major worker caste constituted the highest proportion of the total ingested biomass (38.6%), followed by soldiers (8.2%), alates (3.5%), and minor workers (1.9%) (Fig. 1A). The biomass proportions of consumed ants and termites in each sample are illustrated in Figure 1B, highlighting the variability in the composition of ant and termite taxa.

This study revealed that the prey diversity of juvenile Chinese pangolins ( $7.1 \pm 3.1$  species), which is lower than that of the adult individuals ( $12.4 \pm 4.3$  species) (Sun et al., 2025). Interestingly, invasive ant species constituted a significant proportion of the prey biomass intake. Furthermore, a previous study reported that *O. formosanus* constitutes approximately 40% of the adult pangolin's total consumed biomass (Sun, 2020; Sun et al., 2025). Conversely, juvenile Chinese pangolins in this study consumed significantly less biomass from the alate and minor castes of *O. formosanus*, which suggests a difference in feeding ecology between adults and juveniles. This disparity can be hypothesized to stem from variations in the foraging efficiency and home range between juvenile and adult pangolins.

### Conclusion

This study provides the first report on the prey composition of wild juvenile Chinese pangolins, addressing a significant knowledge gap in the feeding ecology of this Critically Endangered species. The results demonstrate the importance of *O. formosanus* major workers and certain invasive ant species in the dietary composition of juvenile Chinese pangolins. Consequently, these findings provide a valuable reference for improving dietary protocols for young captive individuals and enhancing pangolin rescue efforts.

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## [O\_23] Effects of Agricultural Management Practices on Pangolin Habitats and the Composition of Ants and Termites in Mid-Elevation Orchards in Taiwan

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### Introduction

Agricultural intensification is widely recognized as a major driver of global biodiversity loss, primarily through high chemical inputs and simplified crop systems that reduce habitat heterogeneity and disrupt ecosystem functioning (Benton et al., 2003; Emmerson et al., 2016; Matson et al., 1997; Newbold et al., 2015). These practices create environments characterized by low vegetation cover and homogenized ground conditions, which have negative impacts on soil health and soil biota (Tscharntke et al., 2005), potentially leading to reduced soil invertebrate diversity. In contrast, cover-crop agriculture retains ground vegetation and avoids herbicide use, enhancing soil structure, habitat complexity, and associated biodiversity, and is increasingly regarded as an environmentally friendly alternative (de Pedro et al. 2020; Geldenhuys et al., 2021; Letourneau et al., 2011; Ploeg et al., 2025). Ants and termites are ecologically important soil invertebrates and sensitive indicators of land-use disturbance (Eggleton et al., 1996; Underwood & Fisher, 2006). They also constitute the primary prey of the Critically Endangered Chinese pangolin (*Manis pentadactyla*) (Sun, 2020; Sun et al., 2025). However, how agricultural management influences the availability of pangolin prey in mid-elevation orchard landscapes remains poorly understood.

This study compares forests, cover-crop orchards, and conventionally managed orchards in the mid-elevation region of Dasyueshan, Taiwan. We examine how management practices affect soil pesticide residues, ground vegetation, and ant and termite communities. We further assess how these differences may affect the availability of prey resources for pangolins. Our hypotheses are as follows: (1) Agricultural activities and pesticide use alter soil and vegetation conditions, directly or indirectly influencing ant and termite communities. Thus, we expect negative correlations between (a) the richness and concentrations of soil pesticides, and (b) ground-vegetation diversity, and (c) the diversity of ants and termites. We hypothesize that prey diversity and availability decline along a gradient from forest to cover-crop to conventional orchards.

### Material and Methods

This study was conducted in the mid-elevation region of Dasyueshan, Taichung, Taiwan, where the average elevation of the sites was 884.3m. A total of 15 study areas were established across three habitat types: forest, cover-crop orchards, and conventional orchards. Cover-crop orchards did not apply herbicides and maintained ground vegetation manually, whereas conventional orchards applied herbicides.

Soil samples for pesticide analysis were collected in March 2025 and processed using the QuEChERS method, followed by LC-MS/MS analyses to detect pesticide types and

concentrations. Ground vegetation surveys were conducted from November 2024 to April 2025, with a total of 25 m<sup>2</sup> of quadrats established at each site to record plant composition and cover rates. Ant surveys began in October 2024 and were conducted every two months, for a total of five sampling periods. Each site contained three pitfall trap stations. Additionally, 1500 mL of leaf litter and shallow surface soil were collected for extraction using Winkler bags. Termite surveys were carried out in December 2024 and August 2025. For each survey, three 2 m × 5 m grid plots were established per site, and termite searches were conducted with a standardized two-minute effort per grid.

Heat maps were used to visualize patterns in pesticide types and concentrations among sites. Analyses of vegetation, ant, and termite communities' analysis included the calculation of  $\alpha$ -diversity metrics (Shannon–Wiener ( $H'$ ) and evenness ( $J'$ ) indices). Differences in vegetation composition, and ant and termite assemblages among the three habitat types were assessed using PERMANOVA based on Bray–Curtis distances, with pairwise PERMANOVA applied for post-hoc comparisons where significant differences were detected. Ground vegetations and ant assemblages were visualized using non-metric multidimensional scaling (NMDS). Pangolin prey species were identified based on the foraging ecology study of the Chinese pangolin conducted by Sun et al (2025). Ant and termite species recorded in this study were compared with pangolin preys at the genus level to evaluate potential prey resources across the three habitat types.

## **Results and Discussion**

### **Soil pesticide analyses**

The preliminary results of soil pesticide (including 14 conventional orchard sites and 1 cover-crop orchard site) revealed a total of 29 pesticide compounds detected across the 15 sampling sites. Conventional orchards exhibited both higher pesticide richness and higher concentrations, with an average of 12.2 compounds per site and a mean concentration of 110.4  $\mu\text{g}/\text{kg}$ . In contrast, the cover-crop orchard showed fewer pesticide compounds and lower concentrations (4 pesticide compounds, mean concentration = 17.87  $\mu\text{g}/\text{kg}$ ). These findings represent an initial assessment, and further comprehensive data analysis is currently ongoing to validate these trends.

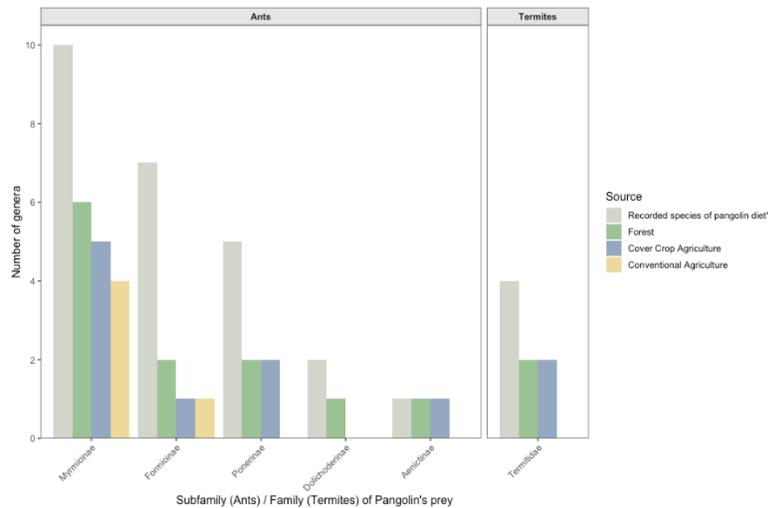
### **Ground Vegetations**

A total of 296 plant species were recorded across all surveys. Cover-crop orchards showed the highest species richness and vegetation cover (164 species, 94.9%), followed by forest sites (160 species, 68.9%) and conventional orchards (80 species, 48.8%). Shannon diversity was highest in cover-crop orchards ( $H' = 1.95$ ), while forest ( $H' = 1.82$ ) and conventional orchards ( $H' = 1.83$ ) were similar. Evenness was highest in conventional orchards ( $J' = 0.71$ ), intermediate in cover-crop orchards ( $J' = 0.67$ ), and lowest in forest sites ( $J' = 0.57$ ). Vegetation composition differed significantly among habitat types (PERMANOVA,  $R^2 = 0.39$ ,  $p = 0.001$ ).

### **Ant and Termite Communities as Potential Food Resources**

Ant surveys recorded 4,447 individuals representing 7 subfamilies, 21 genera, and 32 species across the three habitat types. Ant  $\alpha$ -diversity was highest in forest sites ( $H' = 1.99$ ,  $J' = 0.63$ ), followed by conventional orchards ( $H' = 1.39$ ,  $J' = 0.64$ ) and cover-crop orchards ( $H' = 0.43$ ,  $J' = 0.14$ ). Ant assemblages differed significantly among habitat types (PERMANOVA,  $R^2 = 0.45$ ,  $p < 0.001$ ), with clear separation in community composition in NMDS. Termite surveys documented three species in three genera and two families, with an overall grid-level occurrence rate of 4.8%. Forest sites showed the highest termite occurrence (10.3%) and diversity ( $H' = 1.07$ ,  $J' = 0.97$ ), followed by cover-crop orchards (3.3%;  $H' = 0.50$ ,  $J' = 0.72$ ), while termites were rare in conventional orchards (1.0%; one species;  $H' = 0$ ). Differences in termite assemblages among

habitat types were not statistically significant (PERMANOVA,  $R^2 = 0.37$ ,  $p = 0.16$ ). When compared with pangolin dietary records, the number of prey genera was highest in forest sites (14 genera), followed by cover-crop orchards (11 genera) and conventional orchards (5 genera) (Fig. 1).



This study demonstrates that agricultural management practices strongly influence ant and termite communities, as well as the potential prey resources available to the Chinese pangolin in mid-elevation orchards. Forest and cover-crop orchards consistently supported higher abundance and prey richness of ants and termites than conventionally managed orchards, indicating that reduced chemical inputs and greater habitat complexity play key roles in maintaining soil invertebrate assemblages. Although cover-crop orchards showed lower ant diversity indices ( $H'$  and  $J'$ ), this was largely driven by the high dominance of specific foraging species captured in pitfall traps. This pattern is a known bias of pitfall trapping, where highly active species or proximity to nests can lead to overrepresentation and extreme abundance values, thereby skewing diversity metrics (Bestelmeyer et al., 2000; Gotelli et al., 2011).

The retention of ground vegetation and litter in cover-crop orchards likely enhances soil moisture, microclimatic stability, and resource availability, conditions that favor ground-dwelling invertebrates (Hausberger & Korb, 2016; Jones et al., 2003). In contrast, conventional orchards exhibited simplified vegetation structure and higher pesticide accumulation, which may negatively affect ants and termites through both direct toxicity and sublethal effects on behavior and reproduction (Pisa et al., 2015).

Termite occurrence followed a similar trend, being highest in forest sites and lowest in conventional orchards. In conventional orchards, termites were functionally absent (occurrence rate < 1.0%). This stark contrast in occurrence is a more biologically meaningful indicator of habitat quality than diversity indices, given the extreme scarcity of termites in these chemically managed sites. Although differences in termite assemblages were not statistically significant, the observed pattern suggests that habitat quality and disturbance intensity remain important constraints on termite persistence in agricultural landscapes.

Importantly, differences in ant and termite assemblages translated into variation in potential pangolin prey availability. Forest and cover-crop orchards showed greater overlap with genera

documented in pangolin diets than conventional orchards, highlighting the indirect effects of agricultural management on higher trophic levels. Given the specialized myrmecophagous diet of the Chinese pangolin, agricultural practices that maintain soil invertebrate diversity may improve foraging opportunities and habitat quality within human-modified landscapes (Huang et al., 2025; Karawita et al., 2020; Sun et al., 2025). Overall, our findings suggest that cover-crop cultivation can contribute to biodiversity-friendly agriculture while simultaneously supporting pangolin conservation in mid-elevation regions of Taiwan.

### Conclusion

This study highlights that cover-crop cultivation supports higher availability of pangolin prey compared with conventional orchard management. By maintaining ground vegetation and reducing chemical inputs, wildlife-friendly agricultural practices can enhance soil biodiversity and improve habitat quality for the Chinese pangolin. Promoting such management strategies may contribute to effective conservation within human-dominated agricultural landscapes.

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## [O\_24] Effect of Termite and Ant Abundance on Chinese Pangolin (*Manis pentadactyla*) Activity

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### Introduction

The Chinese pangolin (*Manis pentadactyla*) is a specialized myrmecophage essential for forest ecosystem balance (Sun and Li, 2016). As an endangered species threatened by poaching, habitat loss, and roaming dogs, understanding its habitat selection is critical for conservation. Field surveys are challenged by the species' nocturnal, solitary nature and elusive behaviors. However, pangolins create burrows for foraging and residence (Chao, 1989; Fan, 2005). Foraging burrows predominate and vary seasonally, potentially driven by surface food abundance. We hypothesized that surface food abundance influences pangolin activity: higher termite and ant abundance will correlate with a lower probability of digging burrows but a higher camera trap detection rate.

### Material and Method

**Study Sites and Design:** Surveys were conducted at Huisun Forest Station (central Taiwan, June 2023–May 2024) and Yangmingshan National Park (northern Taiwan, June 2024–May 2025). Forty 10m×10m plots were established at each site. Pangolin activity was monitored via burrow surveys and infrared camera traps over one year. Data on climate, soil, geography, vegetation, and anthropogenic disturbances were collected to analyze habitat selection factors.

**Pangolin Activity Monitoring:** New burrows were recorded seasonally to assess foraging effort. Since burrowing fluctuates seasonally, infrared cameras (height: 10 cm–1 m) were deployed to calculate a seasonal Relative Activity Index (RAI) as a complementary activity metric.

**Food Resource Sampling:** Termites sampling followed Lin and Li (2022). In the middle of each season, ten 1m×1m cells within a 2m×5m subplot were searched (2 mins/cell) using a hoe. Termites were preserved in 95% ethanol and identified morphologically. Abundance was quantified by the number of occupied cells. Ants sampling occurred mid-season using pitfall traps (1m<sup>2</sup> area, 4 tubes) and litter sampling (2L) (Chen et al., 2019). Traps were retrieved after one week, and total individual counts represented abundance.

**Data Analysis:** Seasonal differences in food abundance were tested using the Kruskal-Wallis test. Logistic GLMMs identified factors influencing burrowing probability and camera detection rates. Independent variables (environmental and food factors) were standardized and screened for collinearity (VIF<5). Significant environmental variables were selected via stepwise regression, after which food abundance was added to assess its impact and model improvement (AIC). Analyses were performed in R 4.4.2.

### Results and Discussion

Termite species composition was similar at both study sites, dominated by *Odontotermes formosanus*, *Pericapritermes nitobei*, *Sinocapritermes mushae*, *Nasutitermes parvonasutus*, and *Reticulitermes* spp. Termite abundance showed no significant seasonal variation at Huisun ( $p=0.970$ ) or Yangmingshan ( $p=0.068$ ), though Yangmingshan had lower counts in winter and

spring. Ant abundance peaked significantly in summer at Huisun ( $p < 0.001$ ) and in summer/autumn at Yangmingshan ( $p < 0.001$ ). Regarding pangolin activity, Huisun recorded 30 burrows (winter peak) with a mean Relative Activity Index (RAI) of 68.57, while Yangmingshan recorded 23 burrows (autumn peak) with a mean RAI of 47.51. Logistic regression analysis identified distinct factors influencing burrowing behavior. At Huisun, burrowing was negatively associated with temperature ( $p = 0.019$ ), stone content ( $p = 0.079$ ), and ground cover diversity. Food abundance had a non-significant negative effect, consistent with the hypothesis. At Yangmingshan, burrowing probability increased with rainfall, tree evenness, and distance from hot springs ( $p = 0.047$ ), and decreased with higher soil bulk density and dog presence. Contrary to the hypothesis, food abundance had a non-significant positive effect on burrowing at Yangmingshan. Regarding camera detection rates, Huisun showed positive associations with slope ( $p = 0.012$ ) and canopy openness ( $p = 0.091$ ), and negative associations with elevation and ground cover diversity ( $p = 0.041$ ). At Yangmingshan, detection was primarily influenced by anthropogenic factors. Consistent with our hypothesis, food abundance positively influenced camera detection rates at both sites, although the effect was not statistically significant. The hypothesis that high surface food abundance reduces burrowing was supported only at Huisun. The contradictory trend at Yangmingshan may be attributed to typhoons in late autumn reducing surface insect availability, thereby forcing pangolins to dig more for food. However, the hypothesis that high food abundance increases general activity (camera detection) was supported at both sites. Overall, while food resources play a role, pangolin habitat selection in these shallow mountain forests appears to be more strongly constrained by environmental and anthropogenic factors.

### Conclusion

Pangolin activity is driven less by food abundance and more by climatic, edaphic, vegetative, and anthropogenic factors. Specifically, natural variables dominated at Huisun, whereas human disturbance significantly affected Yangmingshan. However, given the single-year duration and site heterogeneity, these findings warrant conservative interpretation. This study characterizes seasonal food dynamics (termites and ants), establishes survey protocols, and evaluates the relationship between food resources and pangolin activity in shallow mountain forests.

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## [O\_25] Analysis of Seasonal Variations and Influencing Factors in the Fecal Inorganic Matters of the Chinese Pangolin

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### Introduction

The critically endangered Chinese pangolin (*Manis pentadactyla*) is primarily found in low-elevation mountainous regions and hilly areas in Taiwan (Chao, 1989; Sun et al., 2019a). The pangolin is an obligate myrmecophagous mammal that feeds exclusively on ants and termites at all life stages and castes (Swart et al., 1999; Wu et al., 2020), with both groups contributing roughly 50% of the insect biomass in pangolin diets (Sun et al., 2020; Wu et al., 2020). Among termite taxa, the fungus-growing species *Odontotermes formosanus* is the most frequently consumed, accounting for approximately 84.8% of the total ingested termite biomass (Liang, 2016; Sun et al., 2025). The feces of pangolins commonly contain environmental ash elements, such as stones, fine sand, and clay (Sun et al., 2019b, 2019c). This substantial amount of ash ingested during natural foraging provides important insights for formulating appropriate diets for captive individuals. For example, in captive settings, diets with insufficient ash may lead to health and husbandry issues in pangolins, such as diarrhea (Clark et al., 2016). For wild pangolins, the ash content in feces can generally be classified into two sources: 1) Ash derived directly from consumed ants or termites (Brauman et al., 2000); 2) Ash derived from the environment, originating from ant or termite nest materials as well as the surrounding soil, sand, or gravel (Mahmood et al., 2021). However, studies examining ash content in pangolin feces and the seasonal factors that may influence it remain scarce. The aims of this study were as follows: (1) To examine seasonal differences in ash content in pangolin feces; (2) To determine the proportions of fecal ash originating from prey and from the environment; (3) To analyze the correlations between dietary components, seasonal variation, and ash content in feces.

### Material and Methods

#### Fecal processing

The pangolin fecal samples were collected from the Luanshan region (22.53°N, 121.09°E), Taitung County, Taiwan. The study site is characterized by a wet and warm season from May to October and a dry and cooler season from November to April (Lin, 2010; Sun et al., 2020). A total of 85 pangolin fecal samples were processed, and 3 g of each fecal sample was dried at 60°C for 24 hours. After drying, a net weight of 1 g of the dried sample was used for the ashing process, heated at  $575 \pm 25^\circ\text{C}$  for 6 hours, and left to heat overnight (16 hours) until reaching a constant mass. After cooling, the absolute dry weight of the residual ash in the sample was recorded.

#### Data analysis

The total average ash proportion of the fecal sample was calculated on monthly basis and compared by dry and wet seasons. A t-test was then performed to determine the variations of total ash content between dry and wet seasons. Ash content derived from the environment was assessed by subtracting the prey-derived ash to obtain the estimated proportion of ash. To analyze the correlations between prey biomass and ash content in feces, a Pearson correlation analysis was conducted in R, with the level of significance set at  $\alpha = 0.05$ .

## Results and Discussion

Total ash content in the fecal samples

The overall proportion of ash in fecal samples was  $59.1 \pm 13.7\%$  ( $n = 85$ ). In the wet season (May–October;  $n = 38$ ), an average of 65.19% of the dry matter consisted of ash ( $SD = 7.64$ ), whereas in the dry season (November–April;  $n = 47$ ), the mean ash content was 53.02% ( $SD = 16.26$ ), with a statistically significant difference detected between the two seasons ( $t = 3.913$ ,  $p = 0.0113$ ).

### Source of the fecal ash

Notably, the results show that an average of 84.17% of the ash in fecal samples originated from environmental sources, with only about 15% derived from ingested food resources. In addition, in the wet season, environmental ash accounted for an average of 90.44%, whereas in the dry season, the proportion was 79.09%, with statistical significance ( $t = 3.472$ ,  $p = 0.0008$ ).

### Correlation between prey taxa and fecal ash content

The biomass of ant taxa showed a moderate positive correlation with ash content in feces ( $r = 0.301$ ,  $p < 0.001$ ), indicating that the more ants the pangolin consumed, the higher the resulting ash proportion. In contrast, termite biomass exhibited a moderate negative correlation with ash content ( $r = -0.531$ ,  $p < 0.001$ ), suggesting that increased consumption of termites corresponded to lower overall ash content in the feces (Fig. 1.).

This study is the first to report the high ash content in the feces of Chinese pangolins, which can serve as a critical reference for formulating artificial diets for captive individuals. The elevated ash content in the natural diet of wild pangolins likely contributes to its low energy density (McNab, 1984) and may also be associated with the relatively slow growth rate observed in wild populations compared with captive ones (Sun et al., 2024).

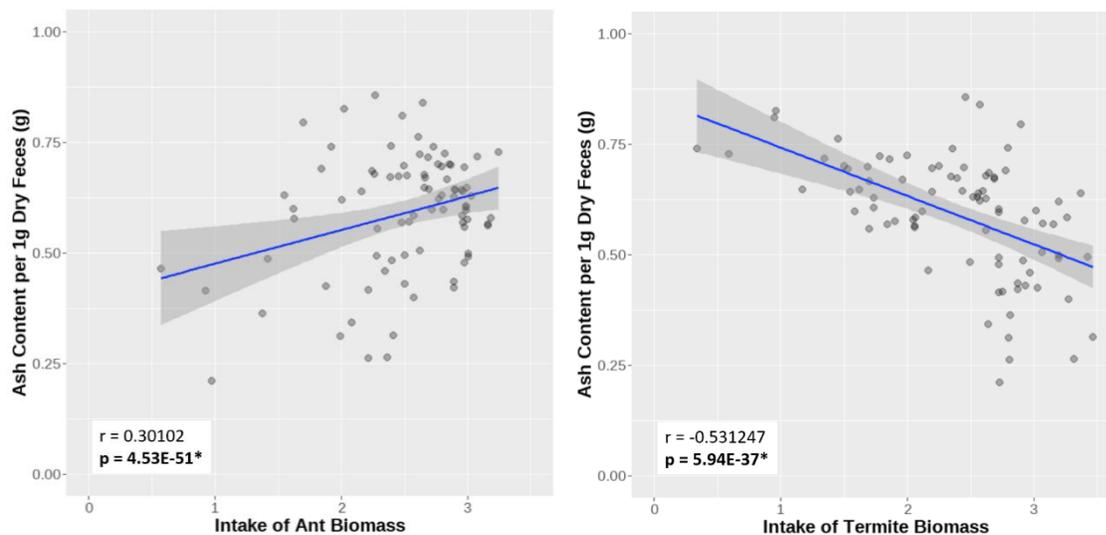


Fig. 1. Correlations between prey biomass and ash content in the fecal samples ( $n = 85$ ) of the Chinese pangolins, analyzed in relation to the intake of ant and termite biomass.

The number of ants (Myrmicinae) consumed is a key factor influencing the ash content in fecal matter. Ant taxa generally exhibit higher mobility when disturbed by pangolin foraging activities compared to termite taxa, making precise prey capture more difficult and thus influencing the ash content in feces. The availability of ant resources in the dry season is lower than in the wet season

(Sun et al., 2025). As a result, pangolins often shift to consuming termite taxa, which contain higher levels of organic matter, as alternative prey during this period (Angelstam et al., 1984). For example, *O. formosanus* accounts for 81.46% of the total biomass intake in pangolin's diet and is the only known fungus-growing termite species in Taiwan. This species constructs fungus gardens by accumulating plant-based substrates to cultivate its symbiotic fungi (Chiu et al., 2019). Such symbiosis results in nest structures, particularly the fungus comb, which contains a substantially higher proportion of organic material compared to the nest environments of other ant or termite taxa. This characteristic may be an important factor in the significant negative correlation observed between the biomass of *O. formosanus* and ash content, thus influencing the overall trend in the data (Fig. 1).

### Conclusion

The study emphasizes the importance of fundamental research in advancing our understanding of feeding ecology and myrmecophagous mammals. The results also provide an important reference for the future formulation of artificial diets for captive pangolins and conservation management.

### Acknowledgement

The authors thank the Department of Wood Science and Design (WSD), and Professor Tung-Lin Wu from National Pingtung University of Science and Technology (NPUST) for providing the site and facilities for fecal processing and technical support.

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## POSTER PRESENTATION

## [P\_01] Preliminary effects of a natural bait on *Coptotermes gestroi*

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### Abstract

Coastal areas on Réunion Island are sensitive, limiting the use of synthetic biocides for termite control. On the west coast, century-old *Casuarina equisetifolia* (filaos) are infested by the invasive subterranean termite *Coptotermes gestroi*. We report preliminary results of a natural-bait field trial using an 8% active polyphenolic pellet formulation converted into a paste and introduced directly into active cavities.

Before field deployment, a laboratory screening (8 weeks; 4 test devices vs 4 controls) recorded complete mortality of exposed termites by week 7. Field monitoring started after a severe nearby building infestation (“Le Bénitier” restaurant) triggered a survey. Fifteen infested trees/stumps were diagnosed using convergent signs (termites in cavities, fresh earthen sheets/galleries, degraded humid wood). Based on the spatial pattern of foci, we assumed  $\leq 3$  major colonies and treated five target trees. Monitoring covered the first four months post-installation with monthly visits. At each visit, 150 g of bait paste was applied per treated tree and recharged as needed; cavities were protected with a UV-resistant adhesive roof. Five control trees received pure cellulose paste in a second zone located ~700 m away.

Across four inspections, three 150 g recharges were needed, indicating consistent consumption. Treated trees showed an apparent activity decrease, with similar trends on some nearby non-treated trees/stumps. At the last inspection, some soldiers from treated cavities appeared less turgid with dull cuticle and altered coloration, suggesting physiological stress. The protocol is being replicated at two additional sites (Saint-Paul sea front; Saint-Denis public garden).

## **[P\_02] Shifts in soil microbial community composition correlated with termite presence in a historic Korean temple environment**

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### **Abstract**

This study aimed to understand the differential termite damage observed among buildings within a Korean temple complex, suggesting that soil microbial community composition influences termite activity. To establish this, wooden monitoring stakes were installed around temple buildings. Soil microbial investigations were performed by comparing soil collected around termite-infested stakes with that from non-infested stakes. Bacterial communities from these termite-associated soil samples were compared using Next-Generation Sequencing (NGS, Illumina MiSeq). For laboratory analysis, the bacterial composition of the field soils was also compared with that of humus soil cultured with termites.

A total of 71,942 and 72,429 high-quality sequences (reads) were identified in the temple's field soil and humus soil, respectively. The dominant phyla in the field soil were Proteobacteria, Firmicutes, and Actinobacteria, while the humus soil was dominated by Bacteroidetes and Proteobacteria. A Principal Coordinate Analysis (PCoA) plot of operational taxonomic unit compositions clearly confirmed that samples separated into soil with and without termites. Specifically, the relative abundance of the Proteobacteria phylum was significantly higher in humus soil cultured with termites than in the control humus soil. These findings suggest a strong correlation between termite presence and shifts in specific soil microbial taxa, providing insight into the varying levels of damage observed across the temple grounds.

### **Acknowledgement**

This research was supported by the Lottery Fund and conducted as part of the research project (NRICH-2505-A62F-1) of the National Research Institute of Cultural Heritage.

## [P\_03] Morphological and Molecular Characterization of a Geographically Isolated *Hodotermopsis* Population from Shikoku, Japan

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### Abstract

*Hodotermopsis sjostedti* is a relict species characterized by a highly disjunct distribution, occurring in patchy and geographically isolated regions restricted to a few locations in Asia. To infer the origin of this species, molecular phylogenetic analyses of *H. sjostedti* populations from China, Taiwan, and the southwestern islands of Japan have previously been conducted. These studies demonstrated minimal genetic differentiation among Japanese populations and supported their monophyly, suggesting that they dispersed simultaneously (Maekawa et al., 1998).

In contrast, the present study focuses on termites collected in Shikoku, Japan, in 2013 (Matsuoka, 2014). Based on morphological characteristics, these specimens were identified as belonging to the genus *Hodotermopsis*, and field surveys confirmed the presence of living colonies at the collection sites. This population is tentatively referred to as “Shikoku-Oo-shiroari” in Japanese and is treated separately from *H. sjostedti* populations from other regions; “Oo-shiroari” means “large termite” in Japanese.

Morphological comparisons revealed clear differences between the two groups, particularly in the coloration, shape, and size of the soldier head capsule. Furthermore, we conducted molecular phylogenetic analyses based on mitochondrial COII sequences to determine the phylogenetic position of the Shikoku population relative to populations from the southwestern islands of Japan. The results showed that the Shikoku population is phylogenetically distant from *H. sjostedti* populations in China, Taiwan, and the southwestern islands of Japan. In addition, a termitophilous rove beetle species was collected from colonies of the Shikoku-Oo-shiroari, and its mitochondrial COII sequence was determined.

Taken together, these findings strongly suggest that the Shikoku population represents a distinct and previously unrecognized species. This study therefore provides an important foundation for future biogeographical and phylogeographic analyses of the genus *Hodotermopsis*.

## **[P\_04] Development of a termite monitoring device based on DEMINL technology with high attractant performance to termites and automatic bait release system**

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### **Abstract**

Termites cause severe economic damages in households, reservoirs, agriculture, and forests. Intelligent termite monitoring technology can enhance the efficiency of termite detection, effectively elevating the professional, informational, and intelligent aspects of termite control in integrated termite management. The automatic termite monitoring stations have been widely applied in China. These stations often show a lower lure effect to termites and the device cannot eliminate termites automatically. Consider this, we identified a chemical compound 'CMA' with high attractant activity to termite, which is convenient to obtain. By adding this substance to bait stations, the attractiveness of termites can be greatly improved, thereby enhancing monitoring accuracy. Secondly, we developed an automatic termiticide release system. Once termites appear and reach a certain number, the alarm within the monitoring device is activated. An electromagnetically controlled puncture mechanism precisely breaches the outer packaging of the termite bait, thereby releasing the active agent for termite elimination. This improved monitoring device can enhance attractiveness and provide possibilities for the integration of monitoring and prevention. At present, this new unmanned device represents a new product in termite monitoring and control.

## **[P\_05] Introduction of Intelligent Termite Monitoring Technology : AI Image Recognition Technology**

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Zhejiang HanDa Environmental Science & Technology Co., LTD

### **Abstract**

Based on the "Termite Crossing" patent for termite activity observation, Zhejiang HANDA Environmental Science & Technology CO., LTD. independently developed a structure, which guides termite activities from the hard-to-detect three-dimensional space to an easy-to-observe two-dimension. Combined with high-definition photography and AI recognition technology, it achieves accurate identification of the species and population size of active termites. This product adopts a modular design, featuring no exposed metal components or wire connections. With a low-power consumption design and built-in batteries that support a single operation cycle of 3–5 years, this device can be used for a long period in complex environments. Applications have already been implemented in many fields such as water conservancy and cultural heritage, for example, at the Beijiang Levee in GuangDong Province and the Jizhou Kiln Site in JiangXi Province.

## [P\_06] Termite Durability of Bifenthrin-treated plywoods of Mixed Tropical Hardwoods - Relevance to Southeast Asia

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### Abstract

Mixed native hardwood species and fast-grown planted tropical woods feature prominently in plywood manufacturing in Malaysia and neighbouring Southeast Asian regions. To enhance the biological durability (especially termite resistance) of such plywoods mainly for indoor aboveground applications, suitable glueline termiticidal veneer treatments have been made during the manufacturing process. A unique 12 weeks H2-Hazard Class termite field test is reported here whereby 5-ply plywoods (11 mm thick) made from mixed less dense hardwoods consisting of pink kedondong (*Canarium* sp.) front face and medang (*Magnolia* sp.) back face was manufactured in Malaysia. The 3 core-ply veneers were essentially of perceived low durability and wood density. The plywood material received glueline protection of 33 g/m<sup>3</sup> bifenthrin (proprietary names Determite™ & PlyGuard™) retention. Similar but untreated mixed hardwoods as well as untreated softwood plywood (5-ply, 12 mm thick) were included in the test for comparison. After the test targeting *Coptotermes curvignathus*, it is shown that both types of untreated plywoods suffered moderate or appreciable attacks with mean AWPA 10-point scale visual termite ratings of 3.2 (softwood) and 8.7 (hardwoods) which contrasts dramatically with bifenthrin-treated hardwood plywood (6 specimens) that were well protected (termite rating ranges: 9.6 - 9.9) which corresponds with extremely low mean mass losses (4.1 - 7.1%; 1917 - 3186 mg) compared with untreated softwood (36.1%; 17606 mg) and untreated hardwood (13%; 6572 mg) plywoods. Among the untreated mixed hardwood plywoods, only the back face medang veneers were termite resistant. Adopting termite rating instead of mass loss as a most reliable indicator of termite resistance, such glueline treated tropical hardwoods with 33 g/m<sup>3</sup> bifenthrin retention thus conferred protection against the voracious *Coptotermes* termites prevalent in Southeast Asian climes.

## [P\_07] Mangiferin and dampwood termites: contrasting behavioural responses in *Prorhinotermes* sp.

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### Abstract

On Réunion Island, subterranean and dampwood termites remain a persistent concern for buildings and coastal habitats. While the invasive subterranean species *Coptotermes gestroi* is still the main driver of structural damage, dampwood-associated *Prorhinotermes* sp. is increasingly encountered in degraded littoral sites where wood remains wet for long periods. Given current constraints on synthetic termiticides, we are exploring locally available plant-derived options. Following a screening of aqueous extracts from 15 local mango varieties (*Mangifera indica*), mangiferin (a C- glucosylxanthone) was selected as a model compound. We ran 96-h contact microcosm assays ( $28 \pm 5$  °C;  $80 \pm 5\%$  RH; darkness) using groups of ~20–25 workers of *Prorhinotermes* sp. and *C. gestroi*. Cellulose beads coated with mangiferin ( $\geq 98\%$  purity) at 1% (w/w) were embedded in moist sand (vehicle-only controls) together with a wood fragment. Mortality and bead interactions (contact, avoidance, detours) were recorded at 24, 48, 72 and 96 h. At 96 h, no clear excess mortality was detected in either species. In contrast, behavioural responses were strongly species-dependent: *Prorhinotermes* sp. rapidly avoided treated beads (detour galleries, minimal contact), whereas *C. gestroi* continued to interact with the treated substrate without obvious avoidance. These results suggest that, at this dose and delivery mode, mangiferin is more promising for localized repellency (barriers/“no-cross” zones) against *Prorhinotermes* sp. than for baiting strategies that rely on ingestion and transfer.

## [P\_08] Local emergence of *Prorhinotermes* sp. in southern Réunion Island: spatial patterns, built environments and implications for integrated management

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### Abstract

On Réunion Island, most management efforts target subterranean colonies of *Coptotermes gestroi*, the main structural pest. However, repeated observations in the commune of Saint-Pierre reveal the local emergence of another subterranean termite of the genus *Prorhinotermes*, which is very rarely mentioned in the global scientific literature. This hygrophilous, photophobic genus is mainly associated with urban “shade–wood–water” contexts (dense gardens, ravines, humid spots). This study combines ORLAT mapping data (2015–2019), targeted surveys (2024–2025), a qualitative assessment of building age at the neighborhood scale, and feedback from companies using bait stations against *C. gestroi*. Occurrences of *Prorhinotermes* were analysed in relation to buildings, landscape structures and the history of baited sites. Results show a strong concentration of *Prorhinotermes* along a west–south–south-east coastal corridor, in neighborhoods of 20–40-year-old detached houses, close to ravines and humid vegetation patches. On several sites, *Prorhinotermes* was detected in stations only after successful control of *C. gestroi*, suggesting either under-detected initial co-occurrence or secondary colonization. Field records also reveal the presence of a second species of the same genus in the area, reinforcing the ecological significance of *Prorhinotermes* in urban environments. At present, no bait active ingredient available on the island has shown convincing efficacy against these *Prorhinotermes* species. These findings highlight the need for specific diagnosis tools and for bait formulations explicitly tested on *Prorhinotermes* to adapt integrated termite management strategies on Réunion Island.

## [P\_09] Connected stations: from bait to termite activity monitoring

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### Abstract

In the control of subterranean termites, bait stations installed in the soil and combined with a cellulosic matrix are widely used for building monitoring and treatment. However, their monitoring mainly relies on periodic inspections, which are often poorly optimized, time-consuming, and provide only limited, discontinuous information between site visits.

This study presents the contribution of a connected electronic device embedded directly into the walls of the bait station, designed for remote monitoring and intended to transform conventional bait stations into field decision-support tools. The device performs periodic measurements representative of the evolution of a physical state within the station. Acquired data are transmitted via a cellular network (4G) to a server hosting an analysis model based on artificial intelligence methods dedicated to termite activity detection.

Based on the monitoring of several stations deployed on infested sites between April and December 2025, the temporal evolution of the measured signals is analyzed and correlated with the local environmental context. The use of the analysis platform makes it possible to discriminate the origin of the observed variations, whether they are related to environmental conditions, operational interventions (inspection, maintenance), or biological activity within the station. In cases of confirmed termite presence, specific and reproducible variation patterns are identified, leading to the triggering of a binary detection indicator (true/false signal).

By providing continuous, easy-to-interpret information (normal status/no activity, activity index) with full traceability, connected bait stations enable improved inspection prioritization, reduced unnecessary field visits, and enhanced documentation of field monitoring and experimental trials.

## [P\_10] Field Performance of Arnica Extract-Based Termiticide from Berkem Biosolutions® - Polyphenolic Plant Extract against Philippine Subterranean Termites

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### Abstract

Subterranean termites are structural pests that caused significant structural damage to homes and wood structures in the Philippines. *Coptotermes gestroi* is responsible to 90% of termite damage in urban and sub-urban areas of the Philippines. Conventional method to control subterranean termites is by injection of liquid termiticide to the soil to establish a toxic or repellent chemical barrier. Plant extracts have been studied in the past as potential sources of alternative insecticides to control termites. A large pool of plant-based materials belonging to the families *Meliaceae* and *Annonaceae* have been investigated for their insecticidal properties. Although these extracts are considered environmentally safer than synthetic insecticides, their commercial use remains limited because environmental factors (temperature, sunlight, and microbial activity) reduce field efficacy. Nevertheless, research continues to explore plant-based chemicals as alternatives or complements to synthetic, including hybrid formulations that combine plant extracts with conventional insecticides. A proprietary termiticide formulation containing Arnica Biosolution – a polyphenolic plant extract developed by Groupe Berkem, France is being evaluated for pre- and post-construction treatment against subterranean termites. Concrete slab test was installed in three high termite hazard sites under non-leaching conditions and termite damage was evaluated annually using the USDA/FS Gulfport Rating system. Initial results showed that 99-100% wood above soil treated with plant extract showed no sign of termite damage. Woods above untreated soil was heavily damaged or destroyed. The formulation performed very well against Philippines subterranean termites; however, more data are needed to fully evaluate its effectivity as a commercial termiticide in the Philippines.



**“Celebrating knowledge, collaboration, and innovation in termite research”**