Innovative Strategies for Termite Management: Development and Evaluation of Effective Baits against *Anacanthotermes turkestanicus*

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Anacanthotermes turkestanicus is a termite species that causes significant damage to wooden structures, cultural heritage sites, and agricultural facilities in Central Asia. Traditional chemical control methods, such as the use of synthetic insecticides, pose environmental risks and often provide only temporary relief. This study explores the development and application of innovative termite bait systems specifically targeting A. turkestanicus. Laboratory and field trials demonstrated the effectiveness of these baits in achieving up to 100% termite mortality. The use of local plant materials such as poplar sawdust and termite sternal gland extracts enhanced bait attractiveness and efficacy, making them a sustainable alternative to conventional methods. These findings suggest that bait-based termite management strategies could provide a more environmentally friendly and effective solution for controlling Anacanthotermes turkestanicus populations in arid regions, reducing the dependency on broad-spectrum chemical insecticides.

Keywords: Anacanthotermes turkestanicus; Integrated pest management (IPM); Termite control, Bait traps; Termite management.

Termites are among the most destructive pests globally, causing extensive damage to wooden structures, agricultural assets, and cultural heritage sites. Their cryptic lifestyle, which involves nesting within wood or underground, presents significant challenges for effective control. Historically, termite management has primarily relied on synthetic chemical insecticides, such as organochlorines, organophosphates, and other compounds. These substances have been used in various formulations, including contact poisons, sprays, foams, and impregnated paints, applied directly to termite nests, infested wooden structures, or surrounding soils. Although effective,

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these chemicals have several drawbacks, including contamination of air, water, and soil, and toxicity to non-target organisms, including humans[1-5].

To improve the application and effectiveness of chemical treatments, various methods have been developed. For example, microencapsulated organophosphates have been used to treat wooden structures, while soil treatments with chemical insecticides have shown some success[6]. Additionally, termite nests have been filled with lethal foams, oils, or fuel oils to block passages and eradicate colonies. Another approach involves fumigation with gaseous agents such as chloropicrin, hydrocyanic acid, or carbon disulfide, which show increased efficacy at higher temperatures due to enhanced termite respiration and gas diffusion. However, the extreme toxicity of these fumigants to humans has limited their practical use in residential settings.

Despite their initial success, these chemical methods often provide only temporary relief and fail to offer long-term control. Since the late 1980s, researchers have explored more sustainable strategies, such as termite baiting systems. These baits typically consist of a cellulose-based matrix impregnated with a toxicant, leveraging the natural foraging behavior of termites. The toxicant-laced bait, placed near termite colonies, is carried back to the nest and distributed throughout the colony, ultimately reaching individuals critical for reproduction and colony maintenance[7].

The efficacy of termite baits depends on several factors, including the composition of the additives, their concentration, and their ratio. Various formulations have been developed, incorporating attractants, pesticides, and matrices that appeal to termites' feeding preferences. These components are often combined with entomopathogenic fungi, bacteria, nematodes, or plant-based termiticides containing substances attractive to termites[9-13]. Baits are advantageous because they require minimal amounts of toxicant, target only the insects that consume them, and minimize exposure to non-target organisms, thereby reducing environmental impact.

For instance, U.S. Patent No. 6,093,389 proposes a composition containing steroid compounds for attracting termites, which avoids the indiscriminate use of large quantities of toxicants[8]. Other formulations have included derivatives of naphthalene mixed with 2-phenoxyethanol to enhance bait attractiveness or repellency[14, 15]. A bait containing bistrifluron, a growth regulator, has been developed in various forms, such as paper, cardboard, wood chips, or sawdust, and has proven effective against several termite species[16, 17]. However, many of these baits have not been tested on specific termite species like Anacanthotermes turkestanicus, which is prevalent in Central Asia and causes significant economic damage in Uzbekistan[18].

Given the limitations and environmental concerns associated with traditional chemical treatments, alternative strategies, such as using biological control agents, have gained interest. Researchers from the Institute of Zoology of the Academy of Sciences of Uzbekistan, in collaboration with Urgench State University, have developed baits using a strain of the fungus Beauveria tenella (strain VD-85) isolated from Central Asian termite populations. The bait demonstrated high efficacy, causing 100% termite mortality in both laboratory and field conditions[25]. Moreover, integrating plant-derived terpenoids, such as knicin and vulgarone B, has shown promise in enhancing insecticidal activity, further expanding the toolkit for sustainable termite management[35, 36].

Despite these efforts, termite populations in affected regions continue to grow, necessitating further research into innovative, environmentally friendly approaches. This study aims to evaluate the effectiveness of novel bait formulations and explore integrated strategies for managing Anacanthotermes turkestanicus in arid environments, considering the adaptability and resilience of termite species developed over millions of years.

MATERIAL AND METHODS

In planning the experiments, we considered the current state and development trends in this area of science, drawing on data from recent domestic and foreign publications. In this project, the termite species Anacanthotermes turkestanicus was used as the object of study. Specimens were collected in the Jizzakh and Navoi districts of Uzbekistan from private houses infested with termites. These included the homes of residents in the village of "Kuksaroy" in the Navoi district, Dashtobod district in the Jizzakh region and Zomin district, Jizzakh region. The wooden frames of these houses were made of poplar logs (Populus spp.), which were heavily damaged by termites. Termites were collected in the spring, summer, and autumn from 2021 to 2023. For laboratory studies, the collected termites were transported to Tashkent in special plastic containers, maintaining appropriate soil moisture and temperature conditions. Moistened hygienic corrugated paper was provided as food for them.

As shown in table [1] 1 compounds 1 to 5 were tested to identify promising agents that could exert chemoreceptive effects in bait traps for termite control. Previous studies[41] have shown that 2-phenoxyethanol, sodium hydroxynaphthalimide, naphthol derivatives, and ethers of ethylene glycol and diethylene glycol possess communication properties against various termite species, including Captotermes formosanus Shiraki, Rhinotermitidae, Kalotermitidae, Captotermes formosanus, Reticulitermes flavipes (Kollar), Reticulitermes virginicus, Reticulitermes speratus, Glyptotermes satsumensis, Glyptotermes fuscus Oshima, and Hodotermopsis japonica, which inhabit different regions of the world. In our study, these substances were tested on the termite species Anacanthotermes turkestanicus.

Within the framework of this project, laboratory-synthesized substances were tested. Despite significant research efforts in various countries, there are currently no simple and reliable criteria for determining resistance to termite damage. Given the complexity of termite control and the substantial financial costs involved, scientists have focused on biological testing. Consequently, the need for highly effective termite control products has increased. Based on numerous laboratory and field experiments and observations, termite poison baits are being developed. The nutritional matrix of these baits as shown in table 2 consists of plants that attract termites and are readily consumed by them.

Our research has shown that poplar sawdust (Populus spp.) is an attractive and acceptable local food additive, which was included in bait matrices for termite control. It is important to note that this type of poplar is commonly used by rural residents as timber frames in the construction of residential houses and is the most accessible and affordable building material. Additionally, the baits were supplemented with an extract from termite sternal glands, which increased the attractiveness of the baits for termites. Thus, we have developed a more improved and cost-effective bait formulation.

The effectiveness of the compounds used was assessed by the size of the eaten area as a percentage relative to the length of the traps. Statistical processing and correlation analysis of the obtained data were performed using the GraphPadPrism 8.0.1 program. The traps were made of pressed cardboard of a cylindrical shape with two open ends with a diameter of 45 mm and a length of 150 mm, which had additional holes on the wall of the cylinder with a diameter of 5 mm for the free entry and exit of termites.

In natural conditions, the effectiveness of the preparations identified in laboratory experiments was tested by burying baits in the soil. Tests were conducted in private homes in several villages of the Navoi and Jizzakh regions, where there was obvious termite infestation.

Three places were selected for testing:

1. Mahalla "Kuksaroy", Khatyrchi district, Navoi region.
2. Mahalla "Yangi hayot", Jizzakh region, Zarbdor district.
3. Mahalla "Istiklol", Zomin district, Jizzakh region.

Bait monitoring was conducted at the end of the experiment's laying period, after which the traps were dug up. Particular attention was given to the presence of mold formation on the traps. The effectiveness of the compounds used was assessed by the size of the consumed area, expressed as a percentage of the total length of the traps. These measurements were used to evaluate the effectiveness of the compounds and are presented in the form of diagrams. Statistical processing and correlation analysis of the data were performed using the GraphPad Prism 8.0.1 software.

RESULTS

Table [1] 3 shows the efficacy of various chemical compounds at a concentration of 0.2% was evaluated against termites over a period of seven days. The number of live termites was recorded at three intervals (Day 3, Day 5, and Day

7), and the percentage reduction in termite numbers was calculated to determine the effectiveness of each compound.

d-Gluconolactone showed moderate activity against termites. By Day 3, the reduction in live termites was 65%, which gradually increased to 64.8% by Day 7. Despite its moderate effectiveness, d-gluconolactone did not achieve complete eradication, suggesting it has limited potential as a stand-alone termite control agent.

2-Mercaptobenzimidazole demonstrated very high efficacy, resulting in a 97% reduction in termite numbers by Day 3. The compound continued to perform well, achieving 99.5% effectiveness by Day 5 and reaching 100% mortality by Day 7. These results indicate that 2-mercaptobenzimidazole is a potent agent for termite control, capable of rapid and complete eradication of termite populations.

2,5-Dimercapto-1,3,4-thiadiazole hydrazine complex also exhibited strong effectiveness, with a 97% reduction in live termites observed by Day 3. The efficacy increased slightly to 97.4% by Day 5 and reached 99% by Day 7, indicating that this complex is highly effective in controlling termite populations and maintaining its efficacy over time.

2,5-Dimercapto-1,3,4-thiadiazole pyridine complex showed moderate effectiveness compared to other tested compounds. On Day 3, a 50.2% reduction in live termites was observed, which increased to 69.4% by Day 5 and further to 90.8% by Day 7. While the pyridine complex did not achieve complete mortality, it demonstrated a steady increase in effectiveness over the duration of the experiment, indicating potential use in integrated pest management strategies.

2-Mercaptobenzoxazole proved to be highly effective, with a 90.9% reduction in termite numbers by Day 3 and 93.4% by Day 5. Complete termite mortality (100%) was achieved by Day 7, suggesting that 2-mercaptobenzoxazole is a promising candidate for termite control due to its high efficacy and rapid action.

The complex of 2,5-dimercapto-1,3,4-thiadiazole with ethylenediamine showed excellent effectiveness, mirroring the performance of 2-mercaptobenzimidazole. A 97% reduction in live termites was observed by Day 3, with near-complete mortality (99.5%) by Day 5 and total eradication (100%) by Day 7. This compound demonstrates significant potential as a termite control agent due to its rapid and sustained action.

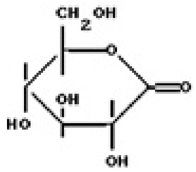
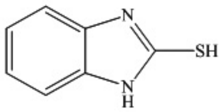
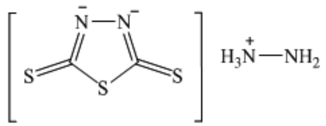
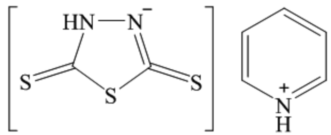
Table 1. Chemical compounds and preparations used in the work

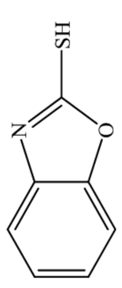
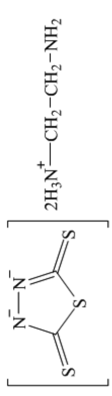
No.	Name of the compound	Means of treatment Laboratory	field	Origin
1	2,5-dimercapto-1,3,4-thiadiazole hydrazine complex	+	+	Synthesized in the laboratory
2	Pyridine complex 2,5-dimercapto-1,3,4-thiadiazolam	+	+	Synthesized in the laboratory
3	Complex 2,5-dimercapto-1,3,4-thiadiazole ethylenediamine	+	-	Synthesized in the laboratory
4	d-gluconolactone	+	+	Synthesized in the laboratory
5	2-Mercapto-benzimidazole	+	+	«Sigma Aldrich»

Table 2. Food bait composition for 5 termite traps

Name of the components of food additives in traps	Mass of additives
Feed - sawdust	200 gr.
water	500 ml
Active ingredient	0,05 gr.
Carboxymethylcellulose	8,0 gr.
Termite Sternal Gland Extract (in Hexane)	50 mkl
Total mass of food in one trap	80 gr

Table 3. Results of testing chemical compounds

	Chemical compound	Concentration %	Before treatment	Live termites after treatment by days of recording, specimens.			Efficiency in %, by days of recording		
				3	5	7	3	5	7
1	d-gluconolactone 	0,02	100,0	92,0±3,5	77,5±1,8	34,5±1,1	6,5	20,9	64,8
2	2-Mercaptobenzimidazole 	0,02	100,0	3,0±0,2	0,5±0.1	0	97,0	99,5	100,0
3	2,5-Dimercapto-1,3,4-thiadiazole hydrazine complex 	0,02	100,0	3±0,1	2,5±0,2	1±0,1	97,0	97,4	99,0
4	2,5-dimercapto-1,3,4-thiadiazole pyridine complex 	0,02	100,0	49±4,5	30±1,1	9±0.5	50,2	69,4	90,8

5	2-Mercaptobenzoxazole 	0,02	100,0	9±1,3	6,5±1,2	0	90,9	93,4	100,0
6	Complex of 2,5-dimercapto-1,3,4-thiadiazole with ethylenediamine 	0,02	100,0	3,0±1,1	0,5±0.4	0	97,0	99,5	100,0
7	Control	Without treatment	100,0	98,4±0.2	98,0±0.3	98,0±0.2			

The control group, which did not receive any chemical treatment, showed minimal change in the number of live termites, confirming a negligible natural mortality rate over the observation period. The number of live termites remained consistent at approximately 98% throughout the experiment, reinforcing the validity of the results obtained for the treated groups.

DISCUSSIONS

The results of this study demonstrate varying levels of efficacy among the six chemical compounds tested for termite control at a concentration of 0.2%. The compounds exhibited a broad range of termite mortality rates, with some achieving complete eradication of termites by Day 7, while others showed moderate to limited effectiveness.

2-Mercaptobenzimidazole, 2-Mercaptobenzoxazole, and the complex of 2,5-dimercapto-1,3,4-thiadiazole with ethylenediamine were the most effective compounds, achieving 100% termite mortality by Day 7. These findings suggest that these compounds have strong potential as termite control agents. The high efficacy of 2-Mercaptobenzimidazole and 2-Mercaptobenzoxazole can be attributed to their sulfur-containing heterocyclic structures, which are known to disrupt essential biochemical pathways in insects. The addition of ethylenediamine to the 2,5-dimercapto-1,3,4-thiadiazole complex may enhance its bioavailability or facilitate its interaction with target enzymes or cellular components in termites, leading to rapid and complete mortality.

The 2,5-Dimercapto-1,3,4-thiadiazole hydrazine complex also showed strong efficacy, with a 99% reduction in termite numbers by Day 7. The hydrazine group in this complex likely contributes to its high potency by forming reactive intermediates that can interfere with vital metabolic processes in termites. The near-complete eradication observed with this compound indicates its suitability for use in termite control applications, especially where rapid action is required.

In contrast, the 2,5-Dimercapto-1,3,4-thiadiazole pyridine complex demonstrated moderate effectiveness, achieving 90.8% mortality by Day 7. Although this compound did not reach the

100% mortality observed with the most effective agents, its steady increase in effectiveness over time suggests that it may act more slowly or require higher concentrations to achieve complete control. The pyridine moiety may alter the compound's mode of action or reduce its ability to penetrate termite cuticles compared to the other tested derivatives. Nevertheless, this compound could still be useful in integrated pest management programs where a gradual reduction in termite populations is acceptable.

d-Gluconolactone was the least effective compound, achieving only 64.8% termite mortality by Day 7. While it did show some capacity to reduce termite numbers, its relatively low efficacy suggests limited potential as a primary termite control agent. The mode of action of d-gluconolactone may not target critical pathways in termites or may require higher concentrations for more effective results. Alternatively, its activity could be due to a more indirect effect, such as acting as a metabolic inhibitor or feeding deterrent, rather than causing direct mortality.

The findings of this study align with previous research demonstrating the potential of sulfur-containing heterocyclic compounds in pest control. Compounds such as 2-Mercaptobenzimidazole and 2,5-dimercapto-1,3,4-thiadiazole derivatives are known for their diverse biological activities, including antimicrobial, antifungal, and insecticidal properties. The efficacy observed in this study further supports their application in termite management, particularly in arid environments where termites like *Anacanthotermes turkestanicus* pose a significant threat.

The highly effective compounds identified in this study have several advantages over traditional chemical treatments. They demonstrated rapid action and high mortality rates, suggesting that they could effectively reduce termite populations with minimal exposure time. Furthermore, the use of sulfur-containing compounds may offer an environmentally friendly alternative to conventional insecticides, which often pose risks to non-target species and the broader ecosystem.

Limitations and Future Directions

While the results are promising, further studies are needed to understand the exact mechanisms by which these compounds exert their effects on termites. Additionally, it would be valuable to assess the long-term efficacy of these compounds under field conditions, including their stability, persistence, and potential impacts on non-target organisms. The development of formulations that maximize their bioavailability and effectiveness while minimizing potential environmental risks is crucial.

Moreover, future research should explore synergistic effects between these compounds and other biological control agents, such as entomopathogenic fungi or nematodes, to enhance overall termite management strategies. Understanding the interaction of these compounds with termite social behaviors and colony structure could also provide insights into optimizing their application in integrated pest management programs.

CONCLUSION

In conclusion, this study identifies 2-Mercaptobenzimidazole, 2-Mercaptobenzoxazole, and the complex of 2,5-dimercapto-1,3,4-thiadiazole with ethylenediamine as highly effective termite control agents, achieving complete mortality by Day 7. These compounds, along with the 2,5-dimercapto-1,3,4-thiadiazole hydrazine complex, show strong potential for use in termite management, particularly in environments where rapid and decisive action is needed. The moderate effectiveness of the 2,5-dimercapto-1,3,4-thiadiazole pyridine complex and the limited impact of d-gluconolactone highlight the need for further investigation into their optimal use conditions. The findings support the continued exploration of sulfur-containing heterocyclic compounds as viable alternatives to conventional termite control methods.

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Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

This statement does not apply to this article.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Author Contributions

Ulugbek Togaev: Writing e original draft, Investigation, Formal analysis, Data curation; Abboskhon S. Turaev: Supervision, Resources, Formal analysis, Data curation, Methodology, Investigation, Funding acquisition, Formal analysis; Vartika Mathur: Supervision, Resources, Funding acquisition; Zoitjon Tilyabaev: Formal analysis, Data curation; Fazliddin Zhaloliddinov: Formal analysis, Data curation; Shukhrat Turageldiyev: Formal analysis, Data curation; Gulnara Shakirzyanova: Data curation; Muhabbat Khashimova: Data curation; Kahramon Rustamov: Data curation; Alimjan Matchanov: Supervision, Resources, Data curation.

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