Termites as source of sciences: An untold tale of termite mounds and beyond

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Abstract: Imagine how thousands of termites respire through the thick-walled mound? How they construct the mound? Social life and Collective behaviour of termites can be utilized as 'Biomimetics' for human well-being. The article explains the biological and behavioural aspects of termite life, and tries to unravel the possible opportunities which the human beings can exploit in various branches of science. The need for research investment and technological advancement to use the knowledge of termites for the benefit of humans is discussed.

Key words: biomimetics, diversity, ecosystem service, stigmergy

Termites usually carry the reputation as enemies of human beings. However one who closely observes and work with them, surely would fall in love with them, as there is a lot to wonder about and learn from termite life and behaviour. Their nest, generally called a mound, is an architectural marvel made of soil and saliva and appears to be like a thick-walled structure, but the gaseous exchange occurs. The social life, long-living queen, foraging strategy, cellulose digestion, symbiotic relationship with microbes, and inquilines they support provides a wealth of information for the benefit of humans. Termites are a classic group of insects which inspires humans as '**biomimetics',** an area of science that is advancing more than ever. It is intriguing to know how termites communicate and inform other members to collaborate and make group decisions.

Winston Churchill, one of the greatest orators of all time, once said, "We shape our buildings, and after that, they shape us". The story goes like this. In October 1943, following the destruction of the Commons Chamber by bombing during the Blitz (a German bombing campaign against the United Kingdom), parliamentarians debated rebuilding the chamber. With the approval of Winston Churchill, the then prime minister, they agreed to retain its rectangular pattern instead changing to a semi-circular or horse-shoe design favoured by some legislative assemblies. Churchill insisted that the shape of the old chamber was responsible for the two-party system, which is the essence of British parliamentary democracy. The design of the section was such that it helped to keep debates lively and robust but also intimate. Termite mounds, with thousands to millions living inside, have long practised the design of their house wherein a unique combination of physical contact and behavioural communication keep the colony intact and robust. Lesson human beings can take in this developed world, where group living is on the wane. The house we live in impacts us; hence, we must construct and manage sustainably without severely hurting natural resources. Each nest has characteristic structures which allow ventilation and cooling. Nests of termites are architectural wonders of the living world, built by the worker's collective performance. Generally speaking, each nest will have a queen, a king, several workers and a few soldiers (Fig. 1), although slight variation occurs in some species. Although known for damaging the wood and wood-based materials in the houses (Fig. 2) and economically important trees in fields, the ecosystem service they provide outweighs the harm they cause. Many soil-feeding species of termites (Fig. 3) add a lot of organic matter to the soil and reported to have enhanced wheat yields by 36 per cent (Evans et al., 2011).

Termites and how they construct mounds can be a source of wisdom. Let us assume a situation where direct sunlight falls on our home that leading to an increased temperature inside the house. We must shell out a lot of money and arrange materials to avoid this direct sunlight. Termite mounds may also face the same problem, which eventually leads to hot air flowing inside the mound. How do termites correct the situation? As the temperature increases in a part of the mound, hot air flows into the mound,

Fig. 1. Different stages and castes of termites

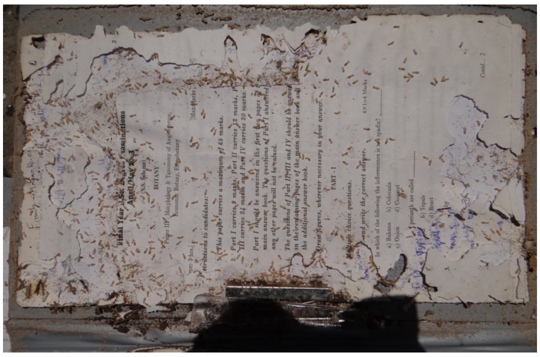

Fig. 2. *Coptotermes* damage on paper

Fig. 3. Soil feeding *Dicuspiditermes*

Fig. 4. The dealate male and female imagoes finding a site for starting a new colony

coupled with increased production of metabolic gases such as carbon dioxide, changing the behaviour of termites. If one section of the mound is too warm, that temperature change will trigger a change in airflow, which will carry construction cues to nearby workers, informing them where to adjust the mound to reduce temperature. The termites will follow their senses to that section and adjust the mound to reduce temperature. Why money and materials? Science helps!

Very little is known about how individually these minute and blind insects come together to construct their mounds. The question is how they achieve this; the term '**Stigmergy**'coined by French biologist Pierre-Paul Grassé in 1959, referring to 'stimulation of workers by the performance they have achieved' explains this phenomenon better. In this behaviour, one worker modifies the environment inducing a change in others. Stigmergy, meaning in simple terms, 'leaving a sign on work in progress,' is a characteristic behaviour that forms basis of termite biology and social life.

The very basic of gathering soil particles and building a mound is stigmergy. When a queen and king start a new colony, initially queen identifies a suitable place (Fig. 4) in the soil and lays fewer eggs. The workers coming from these make their random walks. They

Fig. 5. Variation in head characters which forms the base for taxonomy of termites

Fig. 6. *Neotermes viraktamathi* Ranjith and Kalleshwaraswamy (Kalotermitidae) which the author described from Western Ghats

pick up and drop soil particles, leading to variations in the density of soil particles. During the process, the termites leave a pheromone scent on the soil particles they have carried around, increasing the drop chances of another loaded termite randomly passing by. This behaviour leads to a self-amplification of soil particles, a pile that depletes the free soil grains. The process of amplification and depletion leads to a regular pattern of sand pillars forming their nest's starting point. This explains how the indirect communication among termites via soil particles leads to a collective behaviour in building a mound. In turn, the termite queen communicates with this self-organizing termite-soil system by emitting a pheromone gradient. Now, the same stigmergic principles of termites have been exploited in cellular morphogenesis. A team of interdisciplinary researchers led by Philippe Bastiaens, Director at the Max-Planck-Institute of Molecular Physiology in Germany, have created a life-like proto-cell energized by chemical potential, which is capable of translating external signals into shape changes in dependence on its own self-organized morphology. The scientists idea were confirmed when their lifelike proto-cells showed that the cytoskeleton and signalling system both interact with the membrane to self-organize into various patterns, following the same stigmergic principles as the termite-soil particle system. A clear-cut example of 'Termite based biomimetic exploited in Science' to understand cell to cell interaction.

Does the number of people in the room affect the Air conditioner's performance or cooling effect? We assume that the AC's cooling efficiency depends on the size of the room and the appliance capacity. But the number of people in the room also affects the cooling. Now think of termites, millions of termites respiring and releasing CO_2 from the body. In addition to temperature increase, What if a large quantity of CO_2 accumulates in the mound? Carbon dioxide and an elevated temperature would drastically impact the life of termites inside. Although the temperature of open ventilator mounds and closed ventilation systems differs, most termite species maintain a mound temperature of around 25 degree Celsius. But how do they manage? The termites could achieve this remarkable feat by constantly opening and closing a series of heating and cooling vents throughout the mound over the day. The air enters the lower part of the mound, and they can control the flow of air by adjusting the location and size of tunnels and the height of the mound. Controlling airflow also allows the termites to adjust the temperature and humidity inside the nest. The industrious termites constantly dig new vents and plug up old ones to regulate the temperature. Termites have learnt how to construct their nest efficiently, keeping them ventilated and maintaining the temperature for survival.

Inspired by David Attenborough climbing inside the chimney of a termite nest in Nigeria, Zimbabwean architect Mick Pearce rightly said that evolution had already solved the air conditioning problem. The story began in 1992, when Zimbabwean architect Mick Pearce and his Arup group received a commission to build Eastgate Centre, a two-building office complex and shopping mall, in the country's capital city of Harare. Pearce, however, wanted to do more than build a new building. Eastgate costed 10 per cent less to build than a similarly sized building with air conditioning. The building also used only 35 per cent of energy consumed by comparable buildings in Harare and saved $3.5 million in energy costs in first five years. The Eastgate Centre, made mainly of concrete, has a ventilation system that operates similarly to the termite mound. Depending on which is hotter, the building concrete or the air, the outside air that enters is either warmed or cooled by the building mass. The air thus enters vented into the building's floors and offices before exiting via chimneys at the top. The east gate complex also consists of two buildings separated by an open space covered by glass and open to the local breezes. Fans on the first floor continuously draw air from this open space. Air is then pushed up vertically through the ducts located in the central spine of each of the two buildings. The fresh air replaces stale air that rises and exits through exhaust ports in the ceilings of each floor. Ultimately it enters the exhaust section of the vertical ducts before flushed out of the building through chimneys. Can't we think of building such biomimetic architecture in India, which reduces electricity consumption? Can't we construct climate-responsive buildings which naturally cool down when the ambient temperature is high?

Taxonomy and diversity of termites in India

It is worth remembering two of the greatest termite taxonomists of India who contributed to Indian and world fauna. Dr Mithan Lal Roonwal was the pioneering termite taxonomist in India whose two faunal volumes cover termites of India and adjoining countries. His student Dr Kumar Krishna moved to USA for his Ph D under Dr Alfred E Emerson and contributed to world termite fauna. He published the definitive systematic treatment of the termites of the world in a seven volume *Treatise on the Isoptera* *of the world* in 2013. India has a high diversity of termites, but the Indian termite fauna shares a tiny portion of the global fauna, *i.e.*, approximately 295 species, 52 genera, and six families (Rajmohana et al., 2019; Ranjith and Kalleshwaraswamy, 2021). Among the 295, 188 are endemic to India (Rajamohana et al., 2019). Termites evolved from social cockroaches of the family Cryptocercidae (Blattodea: Blattoidea) (Inward et al., 2007). Hence, termites are now classified under Isoptera, Epifamily Termitoidae within the order Blattodea. There are about 2,937 species of extant termites worldwide (Krishna et al., 2013). Few characters of termites used in termite taxonomy are shown in Fig. 5 for the benefit of readers which represent great diversity among termites.

Ecosystem services of termites

Termites (Isoptera) play essential roles in ecological systems. They are decomposers, especially of a variety of cellulose-based resources, and thus ensure the cycling of organic matter in ecological habitats. The magnitude of ecological role termites play in a habitat is a function of their population density and biomass (Evans et al., 2011). Although both microbes and termites are decomposers, microbes require relatively high amount of water to grow and consume wood, termites can function at relatively low moisture levels, making them an important organisms in tropics. Conservation of beneficial fauna is the need of the hour. Deforestation and urbanization or any other anthropogenic activities could decrease the diversity of termites (Kalleshwaraswamy et al., 2018). Termite species diversity and abundance are linked to historical usage of the land and human activities that alter the landscape and the ecosystem. Ants and termites have similar functional roles to earthworms and provide valuable ecosystem services (Evans et al., 2011). In Addition, they have both direct and indirect benefits to other organisms living in natural systems. But the question is how to balance the agriculture/ urbanization and conservation of termites. Studies need to be initiated to understand the species decline due to human activities and, at the same time, efforts for conservation.

Termites as pests

Many species of termites are serious nuisance organisms, inflicting damage to the wood used in both human-made structures and agricultural and forest environments (Kalleshwaraswamy et al., 2018). The ecology of these termites and ecosystem service they provide must need to be understood. Termites can be grouped into four ecological types: drywood, damp wood, harvester, and subterranean termites. Subterranean termites are comprising of 80% of the economically important species. Unlike drywood termites that are easily transported from region to region, most subterranean species are restricted to their native habitats. In India, the economically important species of termites, *Coptotermes* spp. and *Heterotermes* spp., caused significant damage to timber - in storage and in service. Less than 35 to 40 species have been reported to damage crops and timber in buildings in India (Kalleshwaraswamy et al., 2022).

With the increased trade of wood, more termites are becoming invasive in different countries; India is no exception. Therefore, anticipating this potential mega problem, strict policy measures are vitally necessary (Kalleshwaraswamy, 2022). Termites are identified based on the measurements of body parts of conserved characters such as head length, mandible length etc. which may not be completely correct. Development of molecular tools and automated systems for identification using artificial intelligence may provide better tool for accurate identification.

Termite nest/mound diversity

The species belong to Kalotermitidae (Fig. 6), and some Rhinotermitidae build nests in dead, decaying or living wood (Fig. 7 and 8). The carton nests of *Microcerotermes* (Fig. 9) are common in Parts of Kerala and Karnataka. Most *Nasutitermes* construct arboreal nests on tree trunks (Fig. 10) or in crevices of tree trunks (Fig. 11). Few *Nasutitermitinae* build galleries on the tree trunk, which connect the arboreal nest to soil *Grallatotermes* (Fig. 12) or a few species nest in soil *viz.*, *Trinervitermes biformis* (Fig. 13). Few other groups constructing nests underground are common *viz.*, *Psuedocapritermes* species (Fig. 14). Most species forage by making earthen galleries; however, few are open foragers, *viz.*, *Trinervitermes biformis* (Fig. 15) and *Macrotermes convulsionarius.*

In India, the true mound-builders are mostly belonging to Termitidae family where several species of *Odontotermes* construct earthen mounds. The mound size depends on the colony's age, but the structure of the mound is characteristic. For example, *O. redemanni* (Fig. 16) and *O. brunneus* (Fig. 17) construct multilocular mound with buttresses open to outside, whereas *O.*

Fig. 7. *Coptotermes* species (Rhinotermitidae)

Fig. 10. Arboreal nest of *Nasutitermes*

Fig. 8. *Coptotermes* species construct nest in a piece of wood

Fig. 11. Nest of *Nasutitermes* in a crevice of a tree

Fig. 9. A carton mound of *Microcerotermes pakistanicus*

Fig. 12. Galleries of *Grallatotermes* (Nasutitermtinae) on the tree trunk

obesus construct, unilocular mound without any openings (Fig. 18). However, few African and Australian species make huge mounds and are very characteristic. For example, *Cubitermes,* endemic to Africa, construct gigantic mushroom shaped mounds (Fig. 19). *Nasutitermes triodiae* are known for their "cathedral" shaped giant mounds, often more than 15 feet in height (Fig. 20) found in Australia.

Termites nests horbour inquilines

Many inquilines called termitophiles, live in termite nest, which include a wide range of morphologically and behaviourally specialized organisms. Some species cohabiting in close association with the host colony or occupying nest cavities without direct contact with the host. The strategy of termitophile organisms to become integrated into termite societies include appeasement through chemical, morphological and/or behavioral mimicry. They may be beetles, flies, bugs, caterpillars, mites and millipedes. However, it is not clear whether they are parasites or symbionts. For the reason unknown, many termite species harbour

Fig. 13. Nest entrance of *Trinervitermes biformis*

Fig. 14. Underground nest of soil feeding *Psuedocapritermes* species

Fig. 15. Nest entrance and open foraging of *T. biformis*

Fig. 16. Mound of *O. redemanni*

Fig. 17. Mound of *O. brunneus*

Fig.18. Mound of *O. obesus*

Fig.19. Mushroom shaped Cubitermes nest found in Africa (Photo courtesy Dr Jan Sobotnik)

Fig. 20. Cathedral shaped mound of *Nasutitermes triodiae* found in Australia (Photo courtesy Dr Jan Sobotnik)

numerous parasitic arthropod species, few none. Termite nests provide ideal condition for the survival and resources for these termitophiles. There are no detailed studies in India, the species of termitophiles associated with termites. Among the termitophiles, considerable work has been done on rove beetles (Staphylinidae) which are belong to subfamily Aleocharinae which includes most termitophilous species among arthropods (Mizumoto et al., 2022). Other termitophilous insects are silver fishes, phorids and scarabaeids, but termitophily is advanced in rove beetles (Fig. 21). Most termitophilous rove beetles are associated with foraging termite species. So, there is a necessity of understanding time, stage of entry into termite mound and biology of these insects associated to with termites.

Termite nests are super communities

In any ecosystem, termite activity and their mound support particular species belonging to several kingdoms, notably fungi, plant and animal kingdoms. These organisms in turn act as producers such as phanerophytes, chamaephytes, hemicryptophytes, bulbous, rhizomatous and geophytes. In the second tropic level, consumers such as herbivores, includes leaf-eaters, flower-eaters, fruit-eaters, and even stem-parasites, and carnivores are common (like insects, birds, squirrels, reptiles, mollusca and lichens etc).

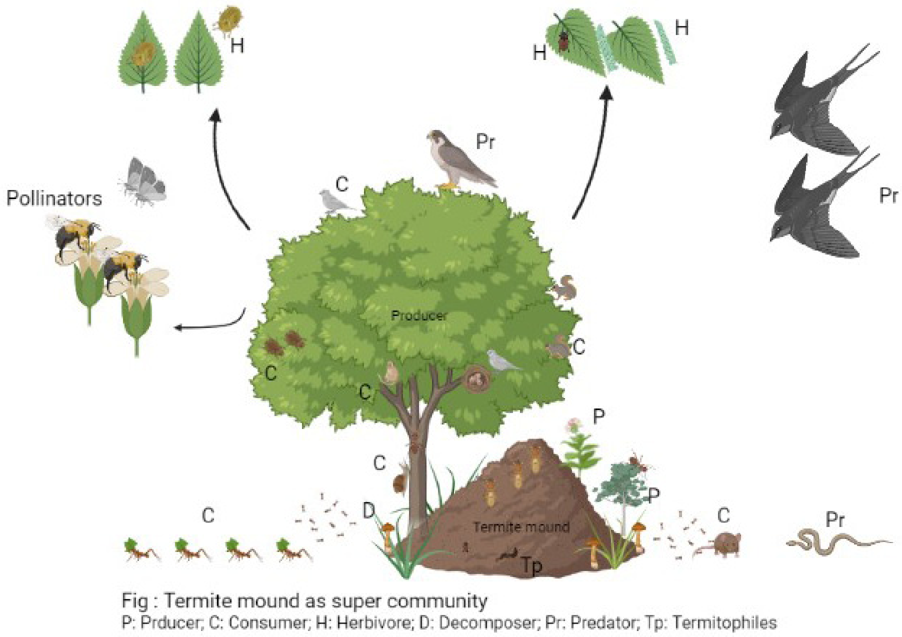

Fig. 21. Supercommunity of termites

Fig. 22. A termitophilic rove beetle in the nest of *Odontotermes* (Photo courtesy Dr Taisuke kanao)

Fig. 23. Defensive secretion from Fontanelle

At third tropic level, decomposers are either animals or fungi (such as mushrooms). Both consumers and decomposers possess their respective predators, which in turn, may be consumed. Parasitism also occurs at different tropic level comprising both endo-parasites and ecto-parasites, such as ticks and insects. Overall, a termite mound supports growth and development of many organisms which are all interlinked forming a complex community, not to forget the microbiota they house inside the gut. The super community of termites is represented in Fig 22.

Termite gut inspired biofuels

Approximately 200 species of microbes live inside the termite hindgut. Their bellies also harbour an array of enzymes which in combination with symbiotic microbes works like bioreactors to produce hydrogen. When termites eat wood and plants, the lignocellulose polymer are broken down into sugars and are transformed into hydrogen. From a small piece of wood, termites while consuming, can produce about a kg of hydrogen which is trapped in the wood. Studies are on the way to use the cocktail of enzymes and gut symbionts for developing efficient renewable energy resources. Genomic studies may further yield efficient way of exploiting termites for commercial biofuel production (Scharf et al., 2011) and hope to exploit this renewable resource through technological advancements.

Termite-inspired Robots

Although human beings are efficient construction engineers, they too face hurdles in the ease of handling materials and the reaching out to difficult terrains where construction work needs to be taken up. Under such circumstances, robots come in handy and can build complex structures without a central controller. Here also, the 'stigmergy' behaviour of termites works without requiring constant human instruction or supervision. A prototype of termite-inspired robots capable of constructing complex structures in remote and hostile locations developed by Harward University in 2014 is a testimony to this area of 'biomimitics' (Gibney, 2014; Korb, 2014). Efforts are underway to use these robots capable of moving sandbags, building leeves in flood-affected areas, carrying food items to the people and so on.

Termites in medicine

Termites are known to have antimicrobial peptides, and in many places worldwide, termites have been used in traditional medicine. In Australia, spinigerin and termicin isolated from *Pseudocanthotermes spiniger*, showed antifungal and antibacterial activity (Coutinho et al., 2008) and are being used in practice known as entomotherapy. They are used to treat various diseases that affect humans, such as influenza, asthma, bronchitis, whooping cough, sinusitis, tonsillitis and hoarseness (Alvae, 2009). The species *Nasutitermes macrocephalus* was the most frequently recorded. It is widely used in Brazil as a therapeutic resource to treat asthma, hoarseness and sinusitis, among other diseases. Another example is *Macrotermes nigeriensis*, used in Nigeria for treating wounds, sickness of pregnant women and as a charm for spiritual protection. In India, there are documents of termites used for treatment of Asthama (Solavan et al., 2006).

Termites as human food

Since time immemorial, India has had many ethno-entomophagic groups restricted to northeast, south and central India. Nevertheless, the diversity of insects consumed is less in south and central India than in the northeast. However, the insect species consumed as food by ethnic people in India are based on availability, palatability, and nutritional values (Chakravorty, 2016). Among insects, around 61 species of termites are considered edible and eaten in many parts of the world (Ramos-Elorduy, 2005). Dewinged termites are considered delicious food in many parts of the world, which may be consumed as a main dish, side dish or snacks (Kinyuru et al*.,* 2009).

Protein-energy malnutrition (PEM) is a significant public health problem in India, especially among young kids. PME affects the child at the most crucial period of development, which can lead to permanent impairment in later life. The underweight prevalence of 42.5% is the highest in the world (Bhutia, 2014). Termites may fulfil the protein requirement, but there is a need for technological intervention where an edible and approved product may fulfil the requirement of young and aged alike. However, until today, a termite-based commercial edible product has yet to be available in India. There is a need to promote termite-based food to serve as an alternative protein source, to remove PEM (De Figueirêdo et al., 2015). Institution-industry collaboration may provide a base for the production of edible dishes such as cookies which could partially support the protein requirement of humans.

Are termites are indicators of ground water?

There are anecdotal stories in villages that farmers' after banking on geologists and native 'dowsers' for finding site for digging bore well have failed, opted for termite mound presence as a cue and found success. As early as 500 CE, Indian astronomer Varahamihira wrote in the *Brihat-Samhita* that termite mounds were indicators of ground water and mineral deposits. There are various literature suggesting a relationship between termite mounds and groundwater. In India, ground water is the most vital and important source for rural livelihood. For farmers, it is costly digging bore wells and any failure is an emotional feeling. In Africa, it is demonstrated that, about 43% of termite mound sites have greater aquifer potential than adjacent areas. One of the primary reasons of enhanced aquifer potential around termite mounds is observed to be the thickness of the weathered layer (saprolite). Termites either have the ability to locate places with deeper weathering horizon or are themselves agents of biological weathering. In Africa, studies have demonstrated that mounds of the genus *Nasutitermes* are usually indicative of promising aquifer potential groundwater reserves compared to macrotermes (Ahmed et al., 2019). Studies of this kind in India need to be initiated, which may identify the potential termite species as an indicator, type of mound and also the success rate.

Termites are critical in natural ecosystems- they help recycle dead wood from trees and plants. Without termites, it would have taken more time for decay or whole world would piled up with dead plants and animals. The benefit accrued from the termites to human beings overweighs the damage they cause. In the recent period, target of termite defensive fluids (Fig. 23) have been tested for household repellents and insecticides (Appalasamy et al., 2021).

Conclusion

Lessons from social insects, especially termites can be applied to solve complex social issues. The super community structural system of self-regulation can be applied to solve complex social issues by understanding the interaction. Individually termite may perform simple behaviour but through collective behaviour they perform complex tasks and have succeeded in the most complex environments. The areas of research are wide and termites provide innumerable opportunities for researchers to understand and use termite biology and behaviour for the benefit of mankind.

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Dr. Kalleshwara swamy CM, Keladi Shivappa Nayaka, Associate Professor of Entomology at University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India works on Insect taxonomy particularly termites and has described two new species of termites, Neotermes viraktamathi (named after his mentor Dr CA Viraktamath) and Ceylonitermellus sahyadriensis from Western Ghat segment of India and a new species of Earwig, Diplatys sahyadriensis (named after Sahyadri hill range of Western Ghats). His studies also document the anthropogenic disturbance in Western Ghats and its negative effect on insect fauna and biodiversity. He was conferred with University Best Teacher Award for the year 2021 in University of Agricultural and Horticultural Sciences, Shivamogga and currently he is handling a project funded by MoEF & CC on 'Taxonomy of termites of south India'. He also trains students interested in termite taxonomy and provides identification services on gratis. Presently he is a postdoctoral researcher at Okinawa Institute of Science and Technology, Okinawa, Japan. His research is focused on understanding the evolution of termites through phylogenomics.