Chapter 2
Termites Identification

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Contents

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Abstract There have been several attempts by taxonomists to identify and trace the phylogeny of termites over the course of time. Termites were previously classified under the order Isoptera because of the equal size of front and hind wings of adult. They are considered as a sister group of primitive wood-dwelling cockroaches and mantids, hence classified under the same superorder, Dictyoptera. However, a molecular phylogenetic study by Inward et al. (Biol Lett 3:331–335, 2007) proved that termites are social cockroaches. The study showed that termites nest within the cockroaches in the phylogenetic tree. Also, wood roach *Cryptocercus* forms a sister group with termites. Hence, termites are reclassified under the order Blattodea and epifamily Termitoidea. At present, 3106 living and fossil termite species have been identified across the world, representing 330 living and fossil genera, under 12 families. In general, the termites can be grouped according to the presence/absence of protozoan in the gut, feeding, and nesting behavior. Only 10% of termite species act as pests either in forest, urban, or agricultural areas. Asian termite pests mainly belong to the family Rhinotermitidae and Termitidae, with species of the genera *Coptotermes*, *Macrotermes*, and *Schedorhinotermes*. They cause serious damages to buildings, crops, and even in plantation forests.

Keywords Taxonomy • Isoptera • Blattodea • Cockroaches • Termitoidea

2.1 Introduction

Taxonomy is the branch of science that comprises nomenclature, classification, and construction of identification key for particular groups of organisms (Quicke 1993). This branch is very important in science because relationship between organisms and its contemporaries can be understood through taxonomy. The combination of traditional taxonomy with theoretical and practical aspects of evolution, genetics, and speciation is known as systematics. These branches have been extensively developed for many insects and especially termites.

Classification of organisms began with introduction of the modern system for naming organisms, known as the binomial nomenclature, by Carl Linnaeus who published the first edition of *Systema Naturae*, a publication related to classification of living forms in 1735 (Krishna et al. 2013a). Since then, he published many editions explaining the classification of organisms. Classification of termites was first explained in his 10th edition of *Systema Naturae* in 1758 (Krishna et al. 2013a). Continuously, taxonomists such as Daniel Rolander, Johann C. Fabricius, Henry Smeathman, Daniel C. Solander, Thomas S. Savage, Johann G. Konig, Carl De Geer, Vincenz Kollar, Pierre A. Latreille, John O. Westwood, Francis Walker, and Gaspard A. Brulle have contributed to the classification of termites, which resulted in the creation of an order specific for termites, Isoptera, in 1832 (Krishna et al. 2013a).

The term Isoptera was derived from the Greek words, *iso*s meaning equal and *pteron* meaning wing, where the adult termites have front wings and hind wings of equal size. Termites, which are also known as “white ants” among the public, however, have no close phylogenetic relationship with ants. Termites are considered as a sister group with a primitive group of wood-dwelling cockroaches and mantids, hence classified under the same superorder Dictyoptera, order Blattodea, and epifamily Termitoidea (Inward et al. 2007).

At present, 3106 living and fossil termite species have been identified across the world, consisting of 330 living and fossil genera and 12 families (Krishna et al. 2013a). However, Mahapatro et al. (2015) mentioned that latest literature reveals record of about 3138 species (fossil and living) worldwide. A constant flow of first descriptions is still increasing this number significantly. Among this, only 10% of termite species are known as pests either in forest, urban, or agricultural areas, such as *Coptotermes* sp. and *Macrotermes* sp., which have caused serious damages to buildings, crops, and even in plantation forests.

2.2 Termite Classifications

There were several attempts made by taxonomists to identify and trace the phylogeny of termites over the course of time. A French entomologist, Gaspard A. Brulle (1809–1873), introduced the term "Isopteres" in 1832, based on equal wings. This classification distinctly differentiated termites from other insects such as Orthoptera, Neuroptera, and Hemiptera. Soon after, this view was adapted and accepted by other taxonomists as order Isoptera (Krishna et al. 2013a).

On the other hand, phylogenetically, the order Isoptera is said to be a sister group with a primitive group of wood-dwelling cockroaches (Blattodea) (Thorne et al. 2000). This is based on the similarity between termites and cockroaches, both the groups being hemimetabolous.[1] Termites have styli in the rear end of the abdomen as in cockroaches (Harris 1957). Furthermore, they enclose their eggs in a specialized case known as "ootheca," similar to cockroaches (Triplehorn and Johnson 2005). Termites are now grouped under the superfamily Blattidae and epifamily Termitoidae (Table 2.1) (Eggleton et al. 2007; Zhang 2011).

Most commonly accepted classifications of termites were proposed by Synder (1949) and Emerson (1955). Synder (1949) produced the "Catalog of termites (Isoptera) of the world," in which he listed about 1773 living and fossil species of

Table 2.1 Classification of termites (Zhang 2011)

Kingdom	:	Animalia
Phylum	:	Arthropoda
Class	:	Insecta
Subclass	:	Pterygota
Superorder	:	Dictyoptera
Order	:	Blattodea
Superfamily	:	Blattoidea
Epifamily	:	Termitoidea

[1] Hemimetabolous = insect gradual development through three stages (egg, nymph, and imago), without pupae.

153 living and fossil genera and 6 living and fossil families. Few changes were made at the family, subfamily, and generic level with revisions produced by Krishna (1970), Harris (1971) and Roonwal and Chhotani (1989). The most updated revision of termite classification was given by Krishna et al. (2013a), who published the seven volumes of the *Treatise on the Isoptera of the World*. The termites were classified into 12 families, with 9 living families and 3 fossil families (Table 2.2), with 330 living and fossil genera and about 3105 living and fossil species, worldwide. Of these, three families are commonly found in Southeast Asia, namely, Kalotermitidae, Rhinotermitidae, and Termitidae.

2.2.1 Kalotermitidae

The morphology, nesting behavior, and social organization of the family Kalotermitidae indicate that it is a primitive group of termites (Krishna 1961). They only feed on damp or decay wood and are referred to as dry-wood termites (Eggleton 2000). Kalotermitidae also are believed to be a sister group to the family Rhinotermitidae and Termitidae. This family is believed to have evolved from the family Mastotermitidae. They are considered as an "evolutionary dead end." This family consists of 21 living genera with 456 species (Krishna et al. 2013b).

They have no distinct nest structures (Tho 1992). In this family the galleries excavated within the wood act as nests. They also consist of small colonies. A distinct soldier caste is present in the colony, but there is no true worker caste (Tho 1992). The role of the worker is carried out by the pseudergates or pseudoworkers, which are morphologically still larva-like, but behaviorally more like workers of higher termites. Many species in this family act as pests and cause serious damage

Table 2.2 Termite families and genera

Families	Subfamilies	Number of genera
†Archeorhinotermitidae	–	†1
Archotermopsidae	–	3 and †1
†Cratomastotermitidae	–	†1
Hodotermitidae	–	3
Kalotermitidae	–	21 and †8
Mastotermitidae	–	1 and †7
Rhinotermitidae	6	12 and †1
Serritermitidae	–	2
Stolotermitidae	2	2 and †1
Stylotermitidae	–	1 and †2
Termitidae	8	236 and †1
†Termopsidae	–	†1

The symbol '†' refers to a fossil family or genera
Krishna et al. (2013a)

to the forest product. *Cryptotermes cynocephalus* Light and *C. domesticus* (Haviland) are the examples of two common species found in Malaysian forest (Homathevi 2003).

2.2.2 Rhinotermitidae

The Rhinotermitidae is a relatively primitive family (Tho 1992) and referred to as damp-wood termites. The family has a worldwide distribution and is considered to have its origin in the Oriental region (Tho 1992). It is believed to have evolved from an extinct ancestral Hodotermitidae. Moreover, this is the most important family of lower termites in Malaysian forest and commonly found in standing or fallen trunks and limbs (Homathevi 2003). There are six subfamilies identified (Tho 1992; Engel et al. 2011): Coptotermitinae, Heterotermitinae, Psammotermitinae, Termitogetoninae, Stylotermitinae, and Rhinotermitinae (Eggleton 2000), comprising 12 genera with 315 living and 18 fossil species (Krishna et al. 2013c). Several of the common genera found in Malaysian forest are *Heterotermes*, *Coptotermes*, *Termitogeton*, *Prorhinotermes*, *Parrhinotermes*, and *Schedorhinotermes* (Thapa 1981; Tho 1992). *Coptotermes curvignathus* Holmgren is an important pest species found in this family that infests rubber and pine trees (Homathevi 2003).

2.2.3 Termitidae

Family Termitidae originated from Rhinotermitidae ancestors and initiated a spectacular adaptive radiation comprising about 75% of termite fauna in the world (Krishna 1970; Wilson 1971). About 85% of the identified Termitidae species are found in Oriental, Ethiopian, and Neotropical zoogeographic regions. In Nearctic and Palaearctic regions, only 17 and 13 species are recorded, respectively. This family is further divided into eight subfamilies, viz., Apicotermitinae, Cubitermitinae, Foraminitermitinae, Macrotermitinae, Nasutitermitinae, Sphaerotermitinae, Syntermitinae, and Termitinae, consisting of 238 living and 1 fossil genus, with 2027 living and 34 fossil species (Krishna et al. 2013d).

2.3 Group of Termites

Other than taxonomic classification, termites are also categorized into general groups, according to the presence or absence of protozoan in the gut, feeding and nesting behaviors, and few other common characteristics.

2.3.1 Lower and Higher Termites

Termites are classified into "lower" termite and "higher" termite, a terminology that refers to their evolutionary level, both as concerns behavior and anatomy. In general, this grouping refers to the symbiotic relationship between termite and protozoans during the digestion process. It is known that digestion in termites is assisted by symbiotic flagellates or symbiotic protists and bacteria living in their gut (Krishna et al. 2013a). This led to their grouping into two categories, which are the "lower" and "higher" termites.

The presence of protists and bacteria is observed in "lower" termites which comprise all the termite families except Termitidae (Carpenter 1989). Presence of symbiotic flagellate protozoans in this group enables the digestion of cellulose in the gut, with the digested food passed on to other colony members by trophallaxis, a transfer process through oral or anal feeding (Mc Gavin 2001).

The family Termitidae is classified as "higher termite" due to the capability to degrade cellulose without symbiotic protists in their gut (Watson and Sewell 1985; Ohkuma 2003). The "higher termites" have a more complex and developed social structure. They also build a more complex and varied nest, compared to "lower" termite (Wheeler 1995).

2.3.2 Feeding Group

Termite foods consist of plant tissues in all stages of decay and also living plants, for certain species. The consumption of plants could be such as standing dead branches, highly decomposed flaky detritus mixed with mineral soil, living shoots and roots, and surface litters of woody twigs, branches, and leaves (Wood 1976; Wardle 1987). Hence, the termites can also be grouped according to their feeding habit and be divided into several types of feeding groups such as wood feeders, soil feeders, litter forages, soil-wood interface feeders, and micro-epiphyte feeders (Eggleton et al. 1997).

Wood feeders feed on wood and woody litters, inclusive of dead branches still attached to trees (Bignell and Eggleton 2000). Termites of this feeding group are the primitive ones (Eggleton et al. 1997). Most "lower" termites are wood feeders. In "higher" termites, wood-feeding species can be found in all subfamilies of Termitidae, except the Apicotermitinae (Bignell and Eggleton 2000). Termite genus *Bulbitermes* is an example of wood feeder (Syaukani and Thompson 2011), although not feeding on living trees but only on dead and decaying woods (Chey 2012).

Another feeding group is the soil feeders, which feed on the upper mineral soil. These types of feeders are only found in Apicotermitinae, Termitinae, and Nasutitermitinae (Bignell and Eggleton 2000). Litter forages, on the other hand, are termites that hunt for leaf litter and small woody items which can be found in different levels of the decaying process. These termites take back the food and store them temporarily in their nest (Eggleton et al. 1997). Examples of litter feeders can be found in the subfamily Macrotermitinae, Apicotermitinae, Termitinae, and Nasutitermitinae (Bignell and Eggleton 2000).

Soil-wood interface feeders feed on highly decayed wood which has turned into friable and soil-like wood. They are also known as “intermediate feeders.” They are found only in Termitinae, Apicotermitinae, and Nasutitermitinae (Bignell and Eggleton 2000). Lastly, the micro-epiphyte feeders usually look up for mosses, lichens, or fungi on tree barks as their food source (Eggleton et al. 1997). *Hospitalitermes* in Southeast Asia, *Constrictotermes* in South America, and *Grallatotermes* in East Africa are examples of micro-epiphyte feeders (Bignell and Eggleton 2000).

In addition, according to Krishna (1970), termites also include another feeding group, the grass feeder. These species consume dung and may sometimes scavenge vertebrate corpse and are usually found at savanna and desert. These feeders play an important role in the Northern Australia’s savanna ecology by processing larger amount of biomass (Termites 2001). Examples are mainly species from the family Hodotermitidae (Krishna 1970).

2.3.3 Nesting Group

Nest building is a natural behavior, often resulting in species-specific architectural behavior (Emerson 1938). All termite species build a nest to house the colony members and protect them (Bignell and Eggleton 2000). The nests range from simple and small excavations to huge subterranean and epigeal systems (Harris 1957). The nesting behavior of termites can be classified into four different nester groups: arboreal, wood, hypogeal or subterranean, and epigeal (Bignell and Eggleton 2000). This behavior is classified according to their habitat, where termites can be found wherever there is timber, decaying wood, epiphytes, and soil.

Arboreal nesters build tree nests made of carton (Fig. 2.1). The genus *Bulbitermes* is an example of arboreal nester. They live in arboreal “stercoral carton” nest

Fig. 2.1 Arboreal nest of *Bulbitermes sarawakensis*

(Lommen et al. 2004). The nest is rounded or elongated in structure and located on a tree trunk, a branch, or in a bush (Weesner 1965). The termites forage through covered runways or "galleries" which connect the nest to the ground (Bignell and Eggleton 2000; Lommen et al. 2004; Chuah 2005). The runways act as protection for the foraging *Bulbitermes* workers and soldiers, sheltering them from attacks by their main invertebrate enemies such as ants (Lommen et al. 2004; Chuah 2005). Other arboreal nesters can be found in genera *Hospitalitermes*, *Nasutitermes*, and *Microcerotermes*.

Beside arboreal nesters, there are several types of nest which could be found among other termite species. Wood nesters (Fig. 2.2) have been identified in Rhinotermitidae and Termitidae (subfamily Termitinae and Nasutitermitinae), which live in or around standing trees or dead logs, without any connection to soil (Bignell and Eggleton 2000).

Hypogeal or subterranean nesters include termites that build their nest below the ground. The most famous example of this nester is the genus *Apicotermes*. The subterranean nest could grow to the size of a football (Bignell and Eggleton 2000; Noirot and Darlington 2000).

Other than that, epigeal nesters are the colony of termites found on the ground, freestanding, or against the side of trees. In this case the nest is known as mound (Fig. 2.3). The mound could vary widely within a genus (Bignell and Eggleton 2000). *Odontotermes grandiceps* Holmgren, *Macrotermes malaccensis* (Haviland), and *Dicuspiditermes* sp. are the examples of termites that build epigeal nests (Noirot and Darlington 2000).

Fig. 2.2 Wood nest of *Bulbitermes* sp.

Fig. 2.3 Nest of *Dicuspiditermes* sp.

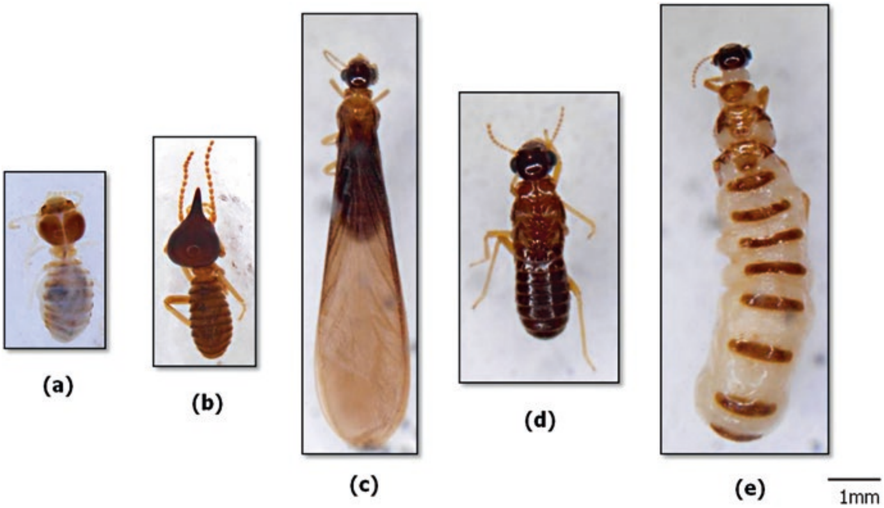

Fig. 2.4 Colony structure of a *Bulbitermes sarawakensis*: (**a**) worker, (**b**) soldier, (**c**) winged reproductive (**d**) king and (**e**) queen

2.4 Identification of Termite Caste

Termites are social insects, like members of the distinct order Hymenoptera such as ants, bees, and social wasps. In general, their social system is formed by three main castes: reproductive (a queen and a king), soldiers, and workers (Fig. 2.4). In addition, there will be a large number of young immature forms in all stages and of all castes (Harris 1957). The number of individuals of each caste varies among species and also depends on the age and size of the colony (Bignell and Eggleton 2000).

2.4.1 Reproductive

Reproductive individuals (also known as alates or royal pair, the king and queen) play an important role. The royal pair can live longer, as long as 50 years (Gibb and Oseto 2006). The king and queen morphology shows wings during their early life, which are lost after dispersing from the original colony (Lewis 1997). They will shed their wings and pair off to search for a suitable harborage to build up a new colony (Ackerman et al. 2009). Figure 2.5 shows the structural morphology of termite imago heads. This structure can be used to identify adult reproductive termites.

2.4.2 Worker

The colony contains high numbers of workers compared to the other castes. The blind workers are also the wingless form of sterile adults. They are also known as helpers or neuter caste (Pearce 1997; Miura et al. 1998), because they give up their

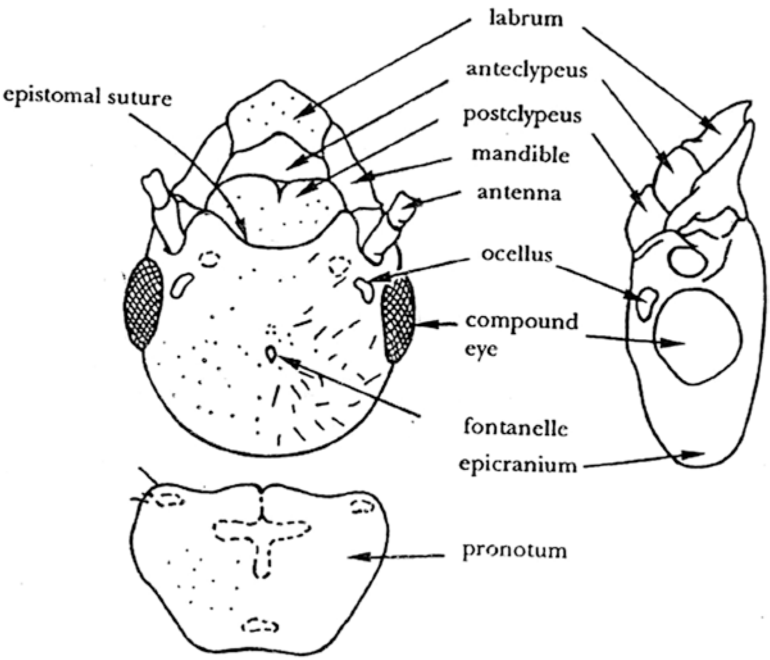

Fig. 2.5 The morphology of termite based on imago head (*Source*: Tho YP; Malayan Forest Records, Forest Research Institute Malaysia, No. 36)

own reproduction to support a number of reproductive individuals. Basically, the workers provide food for the colony, care for the egg-laying queen, and construct new tunnels and chambers (Higashi et al. 2000; Gibb and Oseto 2006). Workers also protect their colony in the absence of soldiers. They use their robust and unspecialized mandibles to attack ants or termites from other colonies, which are their main predators (Noirot and Darlington 2000).

Workers of different termite genera could be identified using mandible characters. The mandible is also useful to differentiate various feeders such as wood, epiphyte, litter, or fungus feeders from soil feeders. Figure 2.6 shows the structure of imago-worker mandibles of soil-feeding termites. The workers and alates have similar mandibles. These have right and left parts which differ in morphology (Fig. 2.6). The left mandible is made up of an apical tooth, a first marginal tooth, a first plus second marginal tooth, a third marginal tooth, a molar tooth, and a molar prominence. The right mandible includes an apical tooth, a first and second marginal tooth, an apical thickening, a molar plate, and a basal notch.

The termite gut structure could also be used to identify the feeding groups (Fig. 2.7). The in situ gut characters and the enteric valve characters can be used to separate the worker caste at a generic level (Ahmad and Akhtar 1981). The in situ gut character (together with the seating of enteric valve) and mandible characters are most suitable for separating genera (especially for the soil-feeding *Capritermes* complex). However, although the enteric valve character is a useful aid for species separation within genera, the use of the enteric valve characters is often limited in small specimen collections.

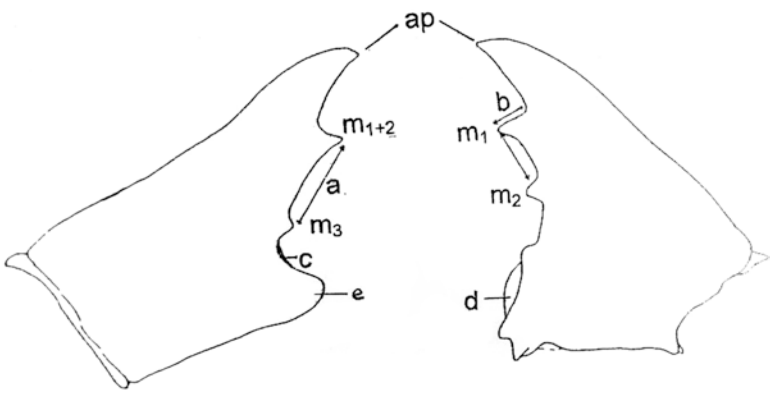

Fig. 2.6 The structure of imago-worker mandibles of soil-feeding termite, left and right: *ap* apical teeth, m_{1+2} fused first plus second left marginal tooth, m_3 third left marginal tooth, m_1 first marginal tooth, m_2 second right marginal tooth, *a* posterior cutting edge, *b* anterior cutting edge, *c* subsidiary tooth, *d* molar prominence, *e* molar plate

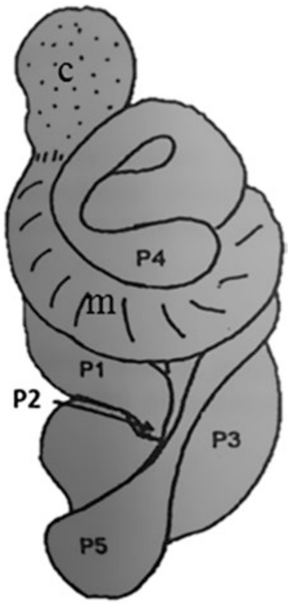

Fig. 2.7 Configuration of the digestive tube in situ, dorsal view: *Termes* spp. *c* crop, *m* mesenteron, *p1* first proctodeal segment, *p2* enteric valve, *p3* third proctodeal segment, *p4* colon, *p5* rectum

2.4.3 Soldier

Termite soldiers are also a wingless form of sterile adults as workers. They usually have stout, triangular, and well-developed mandibles (Harris 1957). In addition, dimorphic soldiers (major and minor soldier) are present in certain termite species, such as in genera *Macrotermes* and *Schedorhinotermes* (Thapa 1981). They play an important role in defending the colony and nest from being attacked by other insects (Gibb and Oseto 2006). They also protect the colony through defensive secretions using the "fontanelle" on their head. In specialized subfamily Nasutitermitinae, the mandibles are replaced with the "nasus," an elongated projection of the "fontanelle" (Tho 1992) (Fig. 2.8).

2.5 Important Asian Termite Pest Species

According to the world termite population, only 10% of their species were identified as pest (Lewis 1997). Wood-feeding subterranean termites are considered as the most destructive insects in the world, because their feeding activity can damage the wooden structures (Hodgson and Roe 2008). This species remains hidden in wood or underground which makes it difficult to find the colony. The estimated number of the pest species is approximately 80 (Grace 2013). Furthermore, some species are closely related to dry-wood termite, Kalotermitidae, and damp-wood species, Termopsidae (Hodgson and Roe 2008).

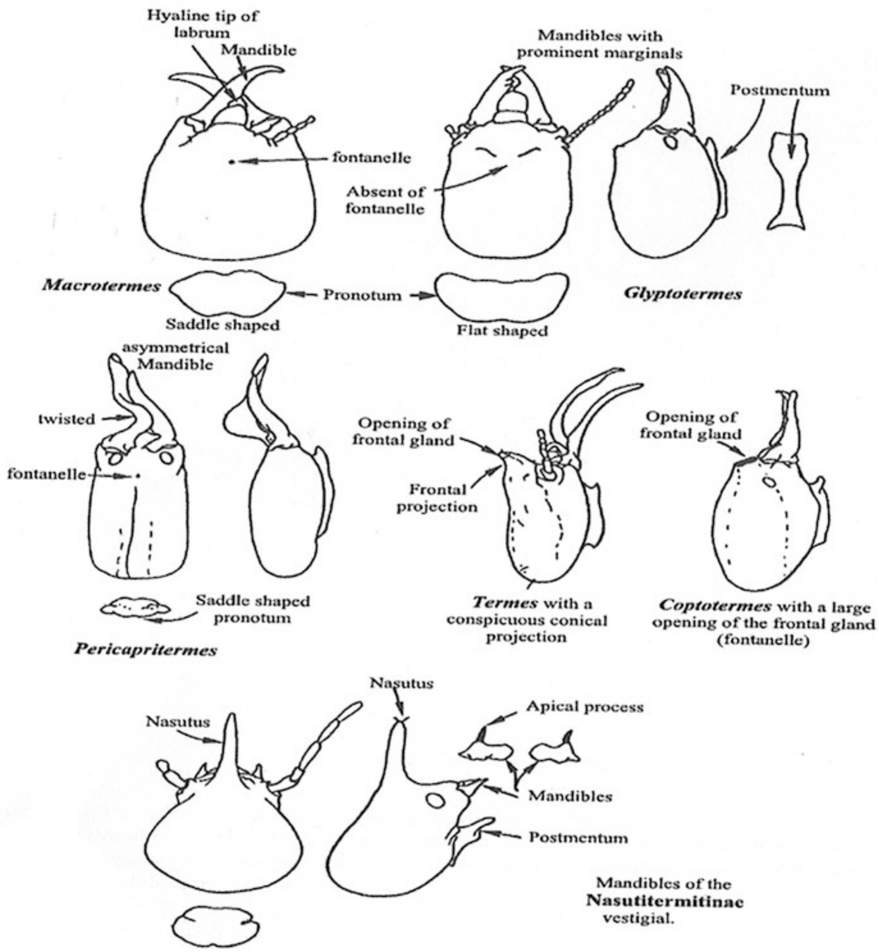

Fig. 2.8 Major characteristics of soldier head (*Source*: Tho YP; Malayan Forest Records, Forest Research Institute Malaysia, No. 36)

Asian pests mainly belong to the family Rhinotermitidae and Termitidae, which consist primarily of pest species of the genus *Coptotermes* (Kirton 2005; Kuswanto et al. 2015). Kuswanto et al. (2015) have concluded that there are five dominant termite species as pests, viz., *Coptotermes* sp., *Macrotermes* sp., S*chedorhinotermes* sp., *Odontotermes* sp., and *Nasutitermes* sp. In Malaysia and Singapore, 12 species of subterranean termites from 7 genera (*Coptotermes*, *Macrotermes*, *Microtermes*, *Globitermes*, *Odontotermes*, *Schedorhinotermes*, and *Microcerotermes*) can be readily found in and around buildings and trees, particularly in suburbia and rural settlements (Chow et al. 2007).

2.5.1 Coptotermes

Coptotermes is one genus closely related with pest (Fig. 2.9). It consists of major pest species causing damage to forest trees and also buildings (Anantharaju et al. 2014; Kuswanto et al. 2015). *Coptotermes* belongs to the family Rhinotermitidae and subfamily Coptotermitinae. There are 67 living and 4 fossil species of *Coptotermes* around the world (Krishna et al. 2013c).

This genus can be identified easily by the soldier head morphology and its behavior toward defense. The soldiers have a unique head shape with an opening (the fontanelle) on the head which looks like a volcano opening. In addition, the soldiers excrete a white fluid from the fontanelle when being disturbed, as a defense mechanism (Bong et al. 2012).

Two major destructive termite pest species in Asia are *Coptotermes gestroi* (Wasmann) known as Asian subterranean termite and *C. formosanus* Shiraki, known as Formosan subterranean termite. These species are native to Asia but have spread to other parts of the world. They look almost similar but can be differentiated under the microscope. The soldiers of *C. gestroi* have much larger head width compared to *C. formosanus* (Hapukotuwa and Grace 2012). The alates of *C. gestroi* have few hairs on the wing, while *C. formosanus* is covered with dense hair on the transparent wings (Li 2009). In the wild, these species can be differentiated by observing their tunnel systems (Hapukotuwa and Grace 2012). The tunnel of *C. gestroi* is much thinner and highly branched with more spatial dispersion, whereas that of *C. formosanus* is wider and less branched, with lesser spatial dispersion compared to *C. gestroi* (Hapukotuwa and Grace 2012).

Fig. 2.9 Soldiers of *Coptotermes curvignathus*

2.5.2 *Macrotermes*

The genus *Macrotermes* is classified in the family Termitidae and subfamily Macrotermitinae, comprising 59 living and 2 fossil species around the world (Krishna et al. 2013d). The unique characteristic of these species is their mounds. They are also known as fungus growers, due to the cultivation of fungi in their mound.

The species of this genus consist of dimorphic soldier and worker castes referred to as major and minor soldiers or workers. Major soldiers have relatively larger head, with well-developed mandibles compared to minor soldiers (Fig. 2.10). Morphologically, the most distinctive character of this genus is the presence of a hyaline tip at the end of the labrum of the soldier caste (Fig. 2.11).

2.5.3 *Schedorhinotermes*

Schedorhinotermes is classified in the family Rhinotermitidae and subfamily Rhinotermitinae. There are 34 living species of *Schedorhinotermes* in the world. This genus is widely distributed, being found in the Ethiopian, Papuan, Australian,

Fig. 2.10 Major (left) and minor (right) soldier of *Macrotermes*

Fig. 2.11 *Macrotermes gilvus* (major soldier)

and Indo-Malayan region (Tho 1992). It can be differentiated from other genera by their body color, smell of the colony, and presence of dimorphism among soldiers.

The *Schedorhinotermes* soldiers are usually yellowish in color when observed with naked eyes. They release their pigments when preserved in 80% ethanol, which tend to change the clear ethanol into yellowish color. Their colony also has a strong, pungent, and repulsive smell, unpleasant to the human nose. This species also consists of two types of soldier caste (dimorphic), which are the major and minor soldiers. According to Walker (2006), major soldiers have bulbous heads with 5–7 millimeter in size. Minor soldiers have relatively narrow heads and more slender mandibles, with 3–5 millimeter in size.

2.6 Conclusion

Correct identification is important to understand the role of any organism in nature, and this statement is valid for termites too. Morphological characteristics and behavior play a very important role in identifying a termite at the genus or species level. Most of the time, identification to species level can only be done by observing the termite's morphological characters under a microscope. Identification to the genus level can be achieved in the wild using the termite's behavioral characteristics, such as food and nesting habits, foraging, smell, and response toward disturbance (defense mechanisms). It is important to know that not all termites are destructive to human. About 90% of their species are beneficial to human and nature. Identification of termites as pest species will be helpful for management and control, either in urban or plantation areas.

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