CHAPTER II

LITERATURE REVIEW

Taxonomy

The order Hymenoptera Linnaeus, 1758, with over 130,000 species, is the third largest order of insects (Romoser and Stoffolano, 1998). The order Hymenoptera is subdivided into 2 suborders; the primitive Symphyta (leaf rolling sawflies, common sawflies), and the highly specialized Apocrita. The Apocrita consists of 2 infraorders (series): Parasitica (parasitic wasps) and Aculeata. The ants, bees and wasps are examples of main families in the infraorder Aculeata. The taxonomic hierarchy of the infraorder Aculeata can be illustrated as follows (Borror, Triplehorn, and Johnson, 1989; Goulet and Huber, 1993; Gauld and Bolton, 1996; O'Toole and Raw, 1999; Elzinga, 2000):

Kingdom Animalia
Phylum Arthropoda
Class Insecta
Order Hymenoptera
Suborder Apocrita
Infraorder Aculeata
Superfamily Chrysidoidea
Vespoidea
Apoidea

Taxonomic note of Chrysidoidea

The members in the superfamily Chrysidoidea (i.e. cuckoo wasps) divides into 7 families which together comprise a holophyletic group within the Aculeata (Bethylidae, Chrysididae, Dryinidae, Embolemidae, Plumariidae, Scleroggibbidae and Scolebythidae) (Goulet and Huber, 1993; Gauld and Bolton, 1996). An estimate of 16,000 species has been reported (Finnamore, 1997).

The both sexes have the same number of flagellomeres of antenna, 8 or 10 segments. The posterolateral apex reaches the tegula and the lobe of their margin is

covered with the spiracle. The posterodorsal margin is shallow and concave. The metapostnotum is short and transversely fuse with the propodeum while the middle of the metapostnotum does not posteriorly expand. Fore wing venation reduces into 3 or fewer cells. Their body is not covered with bristle and the ovipositors are modified as sting (Goulet and Huber, 1993).

Taxonomic note of Vespoidea

The Vespoidea (ants and wasps) have an estimated 48,000 species worldwide (Finnamore, 1997). This superfamily is the largest superfamily in this infraorder which is grouped into 10 families: Bradynobaenidae, Formicidae, Mutillidae, Pompilidae, Rhopalosomatidae, Sapygidae, Scoliidea, Sierolomorphidae, Tiphiidae and Vespidea (Goulet and Huber, 1993; Gauld and Bolton, 1996).

Their body does not have plumose bristle. The flagella of antennae have 10 segments in females, and 11 in males. The posterolateral apex of the pronotum reaches the tegula while the posterodorsal margin is shallow, usually a U-shaped structure. The metapostnotum transversely fuse and expose with the propodeum but the middle of them does not posteriorly expand. Fore wing venations well develop into 9 or 10 cells while hind wing venations have 2 cells and a jugal lobe. The metasomal sterna 1 and 2 are often separated by a constriction. Females have no an articulation within gonocoxite 2 near the base. Ovipositors of some species are modified as sting (Goulet and Huber, 1993).

Taxonomic note of Apoidea

The Apoidea (bees) is the second largest superfamily in this infraorder with an estimate of 28,000 species (Finnamore, 1997). This superfamily consists of 20 families: Ampulicidae, Andrenidae, Anthophoridae, Apidae, Apiformes, Astatidae, Colletidae, Crabronidae, Ctenoplectidae, Halictidae, Heterogynaidae, Megachilidae, Melittidae, Mellinidae, Nyssonidae, Oxaeidae, Pemphredonidae, Philanthidae, Sphecidae and Spheciformes (Goulet and Huber, 1993; Gauld and Bolton, 1996). Bees are divided into 2 groups by their lifestyles: solitary or social. Most bees, including familiar species of bees, carpenter bees and leafcutter bees, are solitary because all females are fertile and there are no worker bees for these species. Their nests were constructed in the ground or other natural cavities. The principal social bees are the honey bees, stingless bees and bumbles. They share a nest, and divide the work of building the nest, caring for the off spring and

foraging for pollen and nectar. They play an important role in the pollination of flowering plants, including ornamental crops, fruit crops, and vegetables (O'Toole and Raw, 1999).

The body of these insects is covered with plumose bristles. The number of flagellomeres is similar to Vespoidea. The posterolateral apex of the pronotum is separated from the tegula by a distinct cuticular gap. The posterodorsal margin is U-shaped while lobe of the posterolateral margin covers the spiracle. Metapostnotum is long and fused with the propodeum but middle of it can posteriorly expand. Wing venation develops into 9 or 10 cells in fore wings while hind wings have 2 cells of venation, and have jugal lobe. The first and second metasomal sterna are often separated by a constriction. Females do not have articulation within the second gonocoxite. Most of their ovipositors are modified as sting (Goulet and Huber, 1993).

Diversity and distribution

The aculeates is comprised of ants, bees and both potter and paper wasps. They are a thermophilous insect that is very sensitive to local microclimates. As a result their nest sites are often situated in specific substrates. They need large areas and a diversity of flowering plants because of their dependence on particular types of flowering plants for feeding; pollen, nectar or prey is another factor in their distribution. Pawlikowski and Hirsch (2002) purposed that the principal factor affecting species diversity in the environments of the lower Vistula Valley was the process of habitat differentiation and the number of flowering plant species. Tropical and subtropical zones have the highest diversity of living creatures in the world, including flowering plants, thus, aculeate bees are distributed throughout most of this area. These insects have significant roles in terrestrial ecosystems, especially in the tropics, acting as pollinators and predators.

In the Neotropical region, aculeate bees are comprised of 25 families, 807 genera and about 13,000 described species. They were represented in the upper Jurassic and most families were common by the Cretaceous. Some of the extant genera appeared between the Paleocene and Miocene (Fernández, 2001). Finnamore (1997) reported that the aculeate bees fauna of five ecozones in the Yukon from north to south: Southern Arctic, Taiga Cordillera, Taiga Plains, Boreal Cordillera, and Pacific

Maritime, contained 153 species. Their study reported species of the following superfamilies; Chrysidoidea (Bethylidae, Chrysididae, Dryinidae and Embolemidae), Vespoidea (Sierolomorphidae, Sapygidae, Vespidae and Pompilidae) and Apoidea (Sphecidae). In the Oriental region, Yamane, Ikudome and Terayama, (1999) reported that species diversity of aculeates were found from the Nansei islands (Japan), consisted of 26 families, 188 genera and 598 species. These indicated the difference in the number of species in each area of the zoogeographical regions. The elevation and latitude are a cause of species diversity of aculeate bees. Finnamore (1997) reported that species numbers of aculeate species was an inverse relationship between 1,500 to 6,050 meters above sea level, where the latitudinal gradient increases the species diversity decreases, with latitude and elevation changes. Araújo, Antonini and Araújo (2006) suggested that the distribution of bee families in southern Brazil also seem to be related to latitudinal gradients. In the Neotropical region, the 3 families; Apidae, Halictidae and Megachilidae have a great proportion of species in tropical areas, and the abundance of them increases with higher latitudes at 1,500 meters above sea level.

Biology

Aculeate wasps are the most advanced group within the Hymenoptera, and are well recognized by the apotypic feature of a modified ovipositor to transmit venom rather than functioning as an egg-positioning device. They also exhibit an array of behavior and life history (Goulet and Huber, 1993; Gauld and Bolton, 1996).

Hymenopteran insects have primary parasitoid strategies termed idiobiont and koinobiont. Aculeate wasps (i.e. cuckoo wasps) are examples of idiobiont ectoparasitoids. Aculeate wasps use the ovipositor to inject eggs into a host like those of the infraorder Parasitica (koinobiont). Their larvae develop and feed on the host from outside the body. The aculeates can sting their preys and inject venom into them. After the preys are paralyzed, they will be carried back to the nests and will be consumed as food by developing offspring (Goulet and Huber, 1993; Gauld and Bolton, 1996; LaSalle and Gauld, 1997).

The aculeates also demonstrate a diverse array of social organization, from solitary wasps to communal nesting bees to highly organized societies of honey bees and ants. Even though, aculeate eggs are laid in a protected and enclosed space similar

to those parasitica eggs, they differ in development patterns in which offspring of the infraorder Parasitica usually live within or upon developing hosts (Goulet and Huber, 1993; Gauld and Bolton, 1996).

Honey bees, stingless bees and ants, including some wasps are social insects. They exhibit complete development or complete metamorphosis which is egg, larva, pupa and adult (Velthuis, 1997; Yamane, Ikudome and Terayama, 1999; O'Toole and Raw, 1999; Nakamura and Sonthichai, 2004). Their colony typically consists of several thousand members that cooperate in nest building, brood rearing and food collection, including nectar and pollen (Michener, 2007). A colony normally has a single queen, thousand workers, and several hundred drones. The social structure of the colony is maintained by the queen and workers and depends on an effective system of communication (Velthuis, 1997). In honey bees, Division of labor within the worker caste primarily depends on the age of the bee but varies with the needs of the colony. Reproduction and colony strength depend on the queen, the quantity of food stores, and the size of the worker force (O'Toole and Raw, 1999; Oldroyd and Wongsiri, 2006).

Morphology

The body of Aculeata (Figure 1) is similar to general insects: head, thorax (mesosoma) and abdomen (metasoma), and is covered by a hard exoskeleton. The first and/or second abdominal segment in some species (ants and wasps) have modified segments as a stalk, called a petiole in the first segment and postpetiole in the second segment (Bolton, 1997; Yamane, Ikudome and Terayama, 1999).

Head

The form of the antennae is particularly variable within the Aculeata i.e. filiform and geniculate. In the most generalized state there are ten flagella. The last flagellum is bent backward, called the antennal hook. The number of antennal segments in the aculeate wasps and bees is generally 12 in the female and 13 in the male, with a few exceptions where antenna is 12 segmented in both sexes of some ant species. On the other hand, it is highly variable in ants, ranging from 4 to 12 segments. The variations in antennal segments are useful in generic classification (Gauld and Bolton, 1996; Yamane, Ikudome and Terayama, 1999; Michener, 2007)

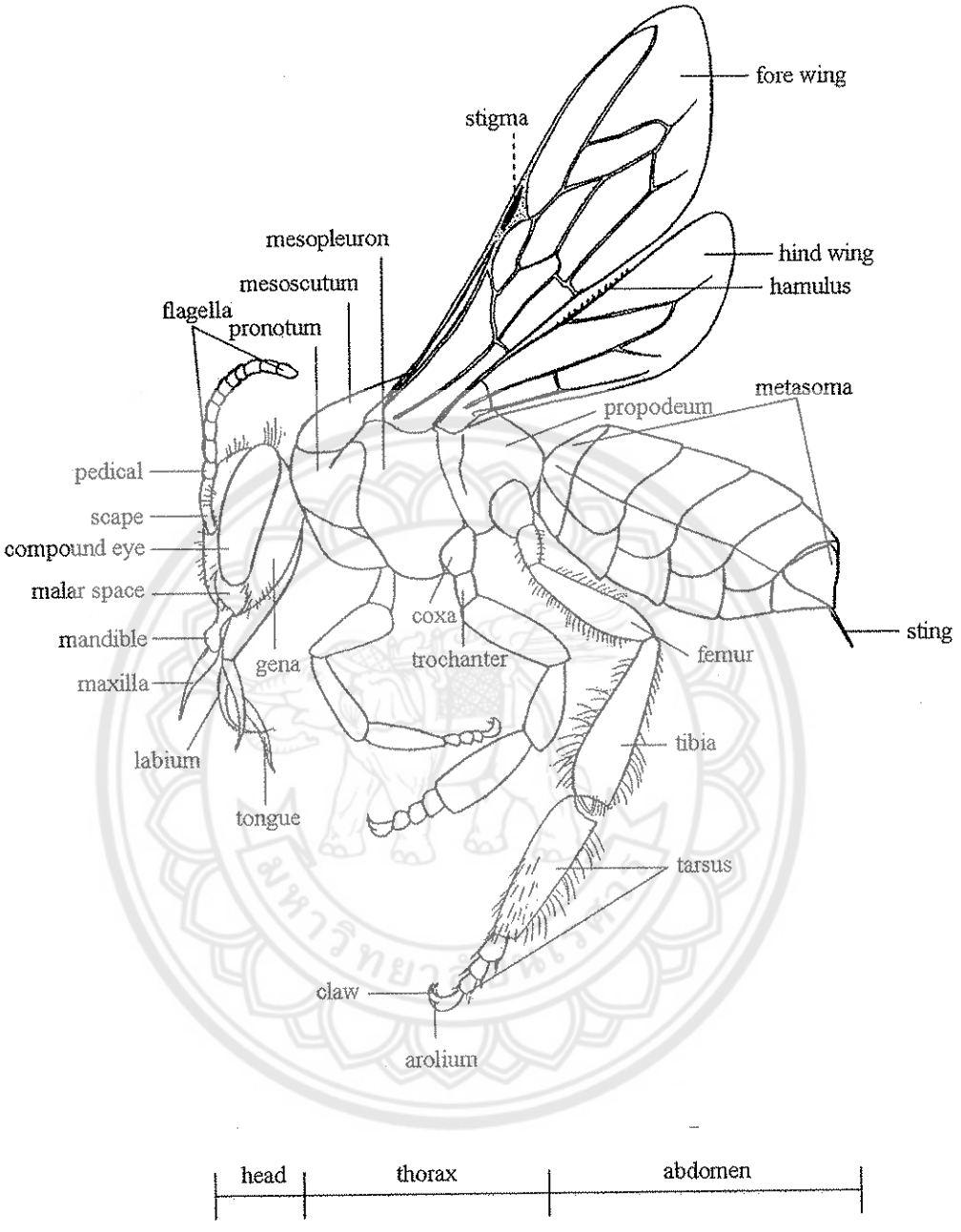

Figure 1 Terminology of the aculeate bee.

Compound eyes and simple eyes (ocelli) occupy lateral portions of the cranium, are generally composed of numerous ommatidia (facets). However, they vary in size and are completely lost in some species of ants. The position and development of eyes are very important in ant classification. The inner margins of the eyes (inner orbital margins) are convex, straight or emarginate. The ocelli are arranged in a triangle shape (anterior ocellus and 2 posterior ocelli). Ocelli may be completely lost in Mutillidae and workers of some ant species (Bolton, 1997; Yamane, Ikudome and Terayama, 1999).

Most mouthparts of the aculeate are complex. They have one to many teeth and/or denticles at the apex and on the inner or masticatory margin, and rarely on the basal or upper margin. They may have an excavation on outer margin or a small fovea basally on the outer face. Maxilla and labium are often modified; their shape is taxonomically very important in the bees. The numbers of segments of maxillary and labial palpi are useful at generic level classification throughout aculeate bees. (Yamane, Ikudome and Terayama, 1999; Michener, 2007).

Thorax (Mesosoma or Alitrunk)

The first segment at the abdomen is united to the thorax to form the mesosoma or alitrunk, with a constriction between the mesosoma and the remaining part of the abdomen in the aculeates (the constriction is not clear in the Symphyta). The last segment of mesosoma is called the first abdominal segment or the propodeum. The 3 segments of the thorax are generally separated from each other by distinct sutures but in some families i.e. Bethylidae, Mutillidae and Formicidae, the sutures are often completely lost (Gauld and Bolton, 1996; Yamane, Ikudome and Terayama, 1999; Michener, 2007).

Some bees have a flat structure (basitibial plate) at the base of the tibiae but some species of non-parasitic bees have long hairs (scopae) mainly on the femur and/or tibiae of legs, or have specially arranged hairs on their legs, pollen baskets (corbicula), for carrying pollen. Cleptoparasitic bees do not have such hairs. Tarsal claws may be simple, bifid, or unidentate to tridentate (Michener, 2007).

The fore and hind wings on each side are held together by numerous small hooks, called hamuli, rising on the anterior margin of hind wing. In many bethylids, most female mutillids and all the worker ants, wings are considerably reduced or

completely lost. The wings are membranous and subhyaline, but often clouded with yellow or black, occasionally with a purple or metallic luster. The reduction in wing venation occurs in nearly all species in this infraorder and much reduce in the Bethylidae, Formicidae and others. The wing cells are the enclosed areas which are very important in Hymenoptera classification. Pterostigma (stigma) is a thickened and darkened area medially on the anterior margin of the fore wings. Reduced veins and no stigma are obvious in hind wings. They may have a basal lobe (anal or jugal lobe) on the posterior margin (Gauld and Bolton, 1996; Yamane, Ikudome and Terayama, 1999; Michener, 2007).

Abdomen (Metasoma)

The abdomen (metasoma) normally consists of 10 segments but this number may not be visible without careful dissection. The first abdominal segment is closely associated with the thorax. The eighth to tenth abdominal segments are reduced and developed into an ovipositor or sting. Thus, only 6 visible segments in the female and 7 in the male are detectable. The metasoma is also called the gaster in wasps and bees, but the term gaster is restricted to the swollen part of the metasoma in ants. In ants, there are 1 or 2 small segments between the mesosoma and gaster which called the petiole and postpetiole. These structures correspond to the second and third segments of true abdomen. Ant gaster consists of third to seventh (eighth in the male), or fourth to seventh (eighth in the male) abdominal segments according to groups. The petiole may have a ventral plate-like process (subpetiolar process), or may be dorsally armed with one or several teeth or denticles called petiolar spines. The last sternum of the male is called the hypopygium or subgenital plate, and any modification of it is useful in classification (Gauld and Bolton, 1996; Yamane, Ikudome and Terayama, 1999).

Body hairs

Insects bear several types of body hair i.e. setae, bristles and pubescence, which in the hymenopteran often adheres to the body surface and may form bands or patches. However, they are often difficult to differentiate setae from pubescence under a dissecting microscope, and any slender flexible filament may be called the hairs. Their color, length, thickness, angle to the body surface, density, condition of apex and arrangement are of taxonomic importance throughout the Aculeata (Yamane, Ikudome, and Terayama, 1999).

Beneficial Aculeates

The Aculeats provide benefits to humans because they are predators of insect pests, pollinators of crops and/or provide natural products.

Aculeates as predators of insect pests

Ants and wasps are known as general predators of insect pests. The ants and wasps (Vespoidea) can paralyze, kill, and collect a large number of insects which they use as food sources for their young (Grabenweger et al., 2005). Ants are extremely abundant in many habitats and are generally predatory insects. For example in the USA, the red imported fire ant, *Solenopsis invicta* is common predators of the cotton aphid, bollworm (*Helicoverpa zea*) and beet armyworm (*Spodoptera exigua*) (Kaplan and Eubanks, 2002).

Aculeates as pollinators

A large proportion of plants that are important to human as food crops (e.g. fruits and vegetables) are pollinated by bees (Ambrose, 1997; Khan and Khan, 2004). Many species of aculeates have a long and pointed tongue which adapted for probing into flowers. Their bodies are covered with branched or feathery hairs. Pollination is a process by the aculeates travel from flower to flower, collecting nectar (converted to honey), and in the process, pick up pollen grains from anthers. In apinie, the pollen is collected on their hind legs which have dense of hairs, referred to as a pollen basket. As the aculeates fly from flower to flower, the pollen grains are transferred onto the stigma of the female flower. This transfer precedes fertilization, in which the pollen tubes grow down the stigma from the implanted pollen grains to the ovary. Cell nuclei from the pollen grain and the ovary then fuse to begin the process of ovulation (Buchmann and Nabhan, 1996; O'Toole and Raw, 1999).

In horticulture, the presence of bees in sufficient numbers is vital for economic crops, particularly as several commercially valuable crops are self-sterile. This is because bees can increase the rate of cross pollination of those economic corps (Gauld and Bolton, 1996).

Aculeates as providers of natural products

The Egyptians practiced apiculture for some 4,500 years ago, and today the honey industry is one of the major world commercial concerns. There is an annual world market of over one million tons of honey. Honey bees provide products such as

honey, beeswax, propolis, bee pollen, royal jelly and venom. Their products are used as food, in traditional medicines, supplementary foods and cosmetics (Goodman, 1991; Gauld and Bolton, 1996; Finnamore, 1997).