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Foraging and Predatory Activities of Ants

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Abstract

Ants are a ubiquitous component of insect biodiversity and well known for its eusocial behavior. They are active foragers, scavengers, and predators that are prevalent in the vicinity of several plantations and crops. They (workers) prey on many insect species and feed on nectar exudates from plants as well as sticky secretions produced by Homopteran and Lepidopteran insects. As ferocious foragers with an aggressive attacking habit (e.g., *Oecophylla smaragdina*), they have often been used as biological control agents against various crop pests. However, some economically important insect species like the wild silkworm, *Antheraea mylitta*, are also affected by these foragers, namely, *O. smaragdina*, *Myrmicaria brunnea*, *Monomorium destructor*, *Monomorium minutum*, etc., which leads to the loss in crop outcome. In addition, some of them are known to destroy several plant species including domesticated fruit trees, particularly at the seedling stage. In this chapter, the foraging habit and the predation biology of these foragers are explored, in which the sequence of attack, their interactions, and invasion caused are discussed. It may also serve as a primary source of information on the foraging and its invasive impact, which may help to protect and/or take counteractive actions against the foragers which are harmful to commercial cultivations.

Keywords: aggressive predator, biological invasions, crop damage, foraging behavior, Tasar culture

1. Introduction

Ants (Hymenoptera: Formicidae) are eusocial cosmopolitan insects with about 13,262 species and 1941 subspecies, classified into 333 genera and 17 subfamilies [1]. They live in diverse habitats with diverse feeding habits and association with other species, in particular, plants and insects [2]. They form various colonies that consist of few to millions of individuals, living in small natural cavities to highly organized vast territories. Colonies comprise castes of sterile,

wingless females such as workers, as well as soldiers and other specialized groups [3, 4]. These ant colonies consist of fertile males, i.e., "drones," and one or few fertile females, i.e., "queens" [3], working together for the colony [5, 6]. Ants have colonized almost every landmass and may form about 15–25% of the terrestrial animal biomass [7]. Their social organization includes the ability to modify habitats and defend themselves. Ants form symbiotic associations with other organisms including other ant species, other insects, plants, etc. Their long coevolution with other species allowed them to enter into such mimetic, commensal, parasitic, or mutualistic relationships [2]. For example, in ant-fungus mutualism, both the species depend on each other for survival. The ant, *Allomerus decemarticulatus*, shows a three-way association with their host plant, *Hirtella physophora* (Chrysobalanaceae), and a sticky fungus helps to trap their insect prey [8]. They may, however, also be preyed upon by other animals as well, although their mimicry (myrmecomorphy), e.g., Batesian mimicry or Wasmannian mimicry (the mimic resembles its host to live within the same nest or structure) may reduce the risk of predation [9, 10]. In terms of their dietary requirements, most of the arboreal as well as some terrestrial taxa forage extensively on carbohydrate-rich plant secretions as well as insect exudates [2, 11]. Aphids and other hemipteran insects secrete a sweet liquid, i.e., honeydew, while feeding on plants. The sugars present in the honeydew are a high-energy food source [12]. Sometimes, the aphids secrete the honeydew for the ants so as to keep their predators away from them. Similarly, ants also tend to mealybugs to harvest their honeydew. Moreover, the myrmecophilous (ant-loving) larvae of the butterfly family Lycaenidae are driven by the ants. The larvae secrete the honeydew from their glands when the ants massage them, while some of them produce sounds and vibrations that are perceived by the ants [13].

As the ants are associated with another organism, they play a significant role in the insect ecosystem. During foraging, they feed on the plant cell sap and the honeydew produced by the other insects. However, they also feed on other insects to complete their food demand. As active foragers, they feed and affect several other commercially important insect species [2, 14–16], including the silkworm, *A. mylitta*, which affects the overall silk production [17, 18].

2. Biology and behavior of ants

2.1. Ants as biological control agent

As predators, ants are important in biological pest control efforts as their prey includes a range of insect species [15, 16]. Based on their foraging habits, the predatory ants can be classified as specialists or generalists [19]. Most of the species are scavengers where they prey on smaller organisms, as well as insect eggs. However, specialist ants do not seem to be significant in biological control measures, although some of them may have an impact on certain specific pests [20]. The generalist ant predators include those that are recognized as important in biological control [15, 16]. Most of the invasive ants are usually habitat generalists that allow them to invade and establish in undisturbed habitats [21]. Indigenous generalist predators have been controlling pests on crops since the dawn of agriculture, and the Chinese have used ant nests in citrus orchards to monitor the pest population [22]. It is

now well documented that ants prey on eggs as well as larvae of numerous pest species in many different countries and habitats [20, 23]. The weaver ant, *O. smaragdina*, is a well-known predator which is used as a biological control agent against various agricultural pest species [20, 24, 25]. Similarly, the small red ant, *Formica rufa* (Linnaeus), is also known to kill many different defoliating pests in European forests [26]. Thus, the predacious generalist ants affect the behavior of prey directly and depress the size of potential pest populations [20, 27, 28]. Although, numerous insects possess generalized defense mechanisms, namely, flight, jumping, or dropping off the plant when vulnerable to attack by their enemies, but these may not be effective against ants that forage at different levels of the ecosystem [29]. The size and other physical attributes also aid in the mechanism of prey defense [27]. In addition, some ants are important in pollination, soil improvement, nutrient cycling, etc. [30]. In contrast, some feed on plants and may act as vectors of some plant diseases, while their attack may also be responsible for causing skin irritation in human beings, domestic animals, and other beneficial organisms [31, 32].

In the Tasar silkworm ecosystem, the worker ants of species such as *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae), *Myrmicaria brunnea* (Saunders) (Hymenoptera: Formicidae), and some *Monomorium* species are frequent foragers which are harmful to the wild silkworm, *Antheraea mylitta*, resulting in losses in wild silk production [17, 18, 33]. The arboreal nature and highly aggressive predatory habit of these species of ants coupled with their extensive foraging on Tasar host plants (e.g., *Terminalia* sp.) often poses a severe risk in Tasar sericulture. Despite the knowledge of relative damage potential of predatory ants in the Tasar silkworm ecosystem, no systematic studies have been reported. Thus, to better understand the foraging and predatory behavior of these ant species on *A. mylitta*, a survey was undertaken in the Tasar rearing fields in Vidarbha, Maharashtra, India [18, 34, 35]. Furthermore, based on the symptoms of attack and predation on *A. mylitta*, the loss was also assessed.

2.2. Tasar silkworm (*Antheraea mylitta*)

The tropical silkworm, *Antheraea mylitta* (Drury) (Lepidoptera: Saturniidae), produces an excellent wild variety of silk, popularly known as "*Tasar* or *Kosa silk*," cultivated traditionally and commercially in India (see Gathalkar and Barsagade [18] for the lifecycle of *A. mylitta*) [36, 37]. The larvae of *A. mylitta* primarily feed on *Terminalia tomentosa* and *T. arjuna* besides several other secondary food plants [36, 37]. Tasar silkworm culture uplifts the socioeconomic status and provides a livelihood security to the stakeholders who are mainly the tribal folks [18, 31, 38]. The rearing of the Tasar silkworm is entirely wild, primarily in forests where it is exposed to various parasites and predators as well as to fungal, bacterial, and viral infections, thereby affecting the sericultural economics and the socioeconomic framework of tribal rearers/farmers [36, 39, 40].

2.3. Field conditions

The Tasar rearing sites of Bhandara (Lat. 21.059972, Long. 79.686987), Chandrapur (Lat. 20.399291, Long. 79.539701), and Gadchiroli (Lat. 20.508963, Long. 79.984988) and

adjoining districts of Vidarbha in Maharashtra, India, were surveyed for studies on foraging and predatory behavior of ants in the Tasar ecosystem during the years 2014–2016. The climatic conditions of Tasar rearing zones were also recorded with the temperature ranging in between 35.5 ± 0.3 and 38.4 ± 0.2°C during the period of the first crop (June-August), 31.8 ± 0.2 and 33.4 ± 0.3°C in the second crop (August-November), and 17.4 ± 0.4 and 21.2 ± 0.3°C in third crop (November-February). The relative humidity was between 87.2 ± 0.2, 90.8 ± 0.6, and 77.2 ± 0.6% during the first to the third crops, whereas the average rainfall was about 362 ± 0.9, 196 ± 0.6, and 39 ± 0.5 mm during the first, second, and third crop, respectively.

2.4. Foraging turns to predation

The social Asian weaver ant, *Oecophylla smaragdina* (Fabricius), can be recognized by its nest building behavior. The workers are very active and fierce, and they are a serious predator of several insect species. They are a very common terrestrial as well as arboreal attacking forager, and, consequently, several studies have been conducted on the foraging behavior of various ant species, including *O. smaragdina* [30]. The highly aggressive feeding habit of *O. smaragdina* in the Tasar ecosystem is a challenge to the Tasar rearers where they attack the early larval instars of the Tasar silkworm, *Antheraea mylitta* [36, 37, 39], thereby affecting overall Tasar silk production. Similarly, the workers of *Myrmicaria brunnea* forages on the ground, leaves, and tree trunks [41, 42] including the Tasar host plants, namely., *T. tomentosa* and *T. arjuna* [18, 34, 43]. They are very aggressive predators and attack the larval stages of *A. mylitta* [34, 44]. While the ant species, namely, *Pheidologeton diversus* (Jerdon) and *Monomorium minutum* (Mayr), are documented as a predator of both Tasar and Muga silkworms [17, 18, 35], *Monomorium minimum* (Buckley) and *Pheidole* sp. attack the temperate Tasar silkworm, *Antheraea proylei* (Jolly) [17], and also *A. mylitta* [43]. Similarly, the ant *Tapinoma melanocephalum* (Fabricius) attacks the pupae and adults of the Muga silkworm [17, 33]. *Polyrhachis bicolor* (Smith) typically drags the spinning larvae in a group [45]. The ant species, namely, *Tetraponera rufonigra* (Jerdon), *Camponotus compressus* (Fabricius), and *Oecophylla smaragdina* (Fabricius), are very frequent foragers in the Tasar rearing fields [17, 18, 33, 34].

2.5. Predatory ants and their invasion in Tasar culture

There are numbers of colonies of predatory ants in the rearing fields of *A. mylitta* (D) in the forest zone of Bhandara, Gadchiroli, Chandrapur, and Gondia districts of Vidarbha, Maharashtra, India. The predatory attack by these predatory ants is very aggressive on the first to the third instar larvae of *A. mylitta* as well as during molting eventually leading to mortality. Their frequent bites on the larval integument and subsequent tearing with its sharp mandibles lead to death of the larvae [18]. Similarly, the small predatory ants (e.g., *Monomorium* sp.) also attack the pupa of *A. mylitta* [35]. However, the predation biology of these ants under field conditions is poorly known. Therefore, in the present chapter, the predation biology of these predatory and highly active foragers is discussed to unveil the risk of predation potential of these species besides the usual foraging habits of the ants.

2.5.1. Oecophylla smaragdina

Oecophylla smaragdina is a very common forager attacking the early (first to third) larval instars of Tasar silkworm, and sometimes it attacks the fourth and fifth instar larvae as well, resulting in massive larval mortality [33, 36, 37]. The life cycle of *O. smaragdina* passes through egg, larval, pupal, and adult stages, and the nest exhibits division of labor with workers (reserve force, defenders, and nurses) and reproductive stages (male and female) [46]. The queen produces hundreds of eggs per day, and the worker population in the colony may total 500,000 offspring from a single queen [47]. The main criteria for separating castes are due to a reproductive capability which distinguishes the workers from the alates (or reproductive), and the males separate from gynes or females within the reproductive caste [48]. The worker ants are responsible for constructing their nest with the leaves of the host plant that is glued together by its larval silk. The workers are dimorphic, namely, major and minor forms, where the major workers are involved in the foraging and nest construction activity, and the minor workers remain in and around the nest, where they are involved in the maintenance of the colony and caring of the queen. In addition, the minor workers hold the larvae during weaving and nest building [49, 50]. *O. smaragdina* shows an extensive foraging for carbohydrate-rich plant secretions as well as insect exudates [2, 11]. Its bite on the human skin is painful due to the toxin sprayed on the wound from the tip of the gaster (e.g., *O. longinoda*) [49, 51]. Due to its far-reaching foraging habits and highly aggressive predatory behavior, *O. smaragdina* is being used as a biological control agent against major pests of economically important crops including many arthropods, acarid, isopod, myriapod, collembolan, termite, beetle, bark lice, and lepidopteran species and annelids like earthworms [20, 24, 52–54]. It can be used against the mango leafhoppers, thrips, fruit flies, tip borers, scale bugs, and mealy bug [55, 56].

2.5.1.1. Predatory behavior of O. smaragdina (worker)

The sequence of attack: *O. smaragdina* (workers) follow the moving larvae and catch the larval appendages like hairs and setae with their sharp mandibles which leads to swelling, paralysis, and later the death of the larvae. Initially, the larva is captured by a single or few workers. Also, as a result of pricking of the integument and subsequent oozing of the hemolymph, the nearby ants are attracted. Often, they also carry the young larvae of *A. mylitta* to their nest (**Figure 1**).

2.5.1.2. Damage caused by O. smaragdina

The attack of *O. smaragdina* is very aggressive; initially, one or very few predators attack the host larva followed by other ants in the vicinity. The ants tear the larva with their strong mandibles, which leads to oozing out of hemolymph and eventually causing larval mortality. The powerful mandibles of *O. smaragdina* are responsible for the painful bite besides irritation caused by the mandibular secretions [2]. The occurrence and subsequent invasion of *A. mylitta* by *O. smaragdina* also depend on abiotic factors like temperature, relative humidity, and rainfall. The attack of *O. smaragdina* on *A. mylitta* results in 4–5% loss in Tasar sericulture [18, 34].

Figure 1. Predation of *A. mylitta* by *O. smaragdina* showing (a) colony of *O. smaragdina* on Tasar host plant (*T. tomentosa*) and (b and c) predatory attack on early larval instars of *A. mylitta*.

Figure 2. The predatory attack of ant *M. brunnea* (a) on a small insect, (b) on the larva of *A. mylitta* on the tree trunk of host plant, and (c) on the larva of *A. mylitta* on the Tasar ground (field) (source: Gathalkar and Barsagade [43]).

2.5.2. Myrmicaria brunnea

Myrmicaria brunnea of subfamily Myrmicinae has a distinctively curved abdomen and two spines on the metathorax. Workers are chestnut brown with shining mandibles. The genus *Myrmicaria* is predominantly a honeydew feeder and scavenger, which builds underground nests. Some species of *Myrmicaria* are highly predatory, foraging in groups and moving in a sinuous path with widely opened antennae [57]. It is a dominant predator of many insect species, including the larvae of *A. mylitta* besides earthworms.

The workers of *M. brunnea* were found to forage on the Tasar host plants, *T. tomentosa* and *T. arjuna.* It builds ground nests under the Tasar host plant, and it shows terrestrial as well as arboreal scrounging propensity. They suck the cell sap from the leaves (ventral side) of Tasar host plant, and during sap sucking, they also attack small insect species (**Figure 2(a)**) as well as larvae of Tasar silkworm (**Figure 2(b)** and **(c)**). Initially, the Tasar larvae are captured by a few workers and subsequently pricked, thereby attracting other workers nearby the site of attack.

The workers are highly aggressive, cut their prey into small pieces, and later on transport them to their ground nest, and sometimes the whole prey is also transported to the nest (**Figure 2(c)**). Sometimes, these predatory ants carry their prey to their ground nest either after cutting into small pieces or the whole prey including the fourth/fifth instar larvae of *A. mylitta*.

Being aggressive, the predation activity of *M. brunnea* and weaver ant, *O. smaragdina*, shows remarkable similarities in Tasar rearing also [34, 58–60]. The ant, *M. brunnea* (Saunders), has a geniculate type of the antenna which is characteristic of aculeate Hymenoptera [55, 56, 61]. A ball-like scape at the base region present in the ants, *Diacamma* sp. and *Camponotus japonicus* Mayr [55, 61], is also observed in *M. brunnea*. The pedicel in *M. brunnea* is long and broad with an imbricate surface and covered with patches of sensilla, similar to *C. japonicus*, *C. sericeus* [56, 61], and *C. compressus* [33].

The mouthparts of the ant species are well developed and adapted for grasping and feeding on the host species. The mandibles in *M. brunnea* are potent tools for prey catching, fighting, digging, wood-scraping, grooming, brood care, and trophallaxis [2, 62]. The abundance of *M. brunnea* in Tasar rearing fields is a serious issue, which affects the total Tasar silk production [18]. Predation by *M. brunnea* was also recorded on Muga silkworm, *A. assamensis* [17].

2.5.2.1. Feeding behavior (Myrmicaria brunnea)

The attack and feeding pattern of this ant are very aggressive. Initially, one or very few ants attack the larva of *A. mylitta*, and, subsequently, other members of the colony join the group for feeding (**Figure 2**) [43]. As feeding progresses, the ants tear the host larva with their robust and sharp mandibles due to which hemolymph oozes followed by the complete destruction of the prey (Supp. Info. video clip 1 (can be viewed at https://youtu.be/q8WfVBLLlvA). The ant, *M. brunnea*, usually attacks the early instars of Tasar silkworm; we also observed them to attack the fourth and fifth instar larvae (**Figure 2(c)**). During feeding, the larvae of *A. mylitta* often fall to the ground which are then attacked by these ants. They may consume the whole prey at the site, or they drag their prey to their ground nest (**Figure 2(c)**) (Supp. Info. video clip 2 (can be viewed at: https://youtu.be/JsbbiWeZOw0)). During the predatory attack, the Tasar host larvae try to escape, but the intensity of injuries and constant biting by the ants make the larva defenseless, resulting in complete larval invasion and eventual death.

2.5.2.2. Damage (crop loss)

The mean percent of larval mortality of *A. mylitta* due to the attack by *M. brunnea* (workers) was calculated, and the year-wise mortality was about 3–5% of total crop damage (**Figure 3**) [18, 43].

2.5.3. Monomorium sp.

The myrmicine genus, *Monomorium*, includes the small-sized ants, reddish-brown in color, and belongs to the family Formicidae. There are about 358 species in which the genus *Monomorium* includes 27 subspecies [63]. They represent one of the most influential groups of ants due to its abundant diversity and intra-morphological and biological variability [64]. Of these, *Monomorium pharaonis* (Linnaeus), *Monomorium destructor* (Jerdon), and *Monomorium floricola* (Jerdon) are well-known household pests [65]. As a predator of various pest species, they are often used in pest management programs. The predatory habit of ants has a major influence in many habitats [66, 67]. Thus, some ants are biologically essential
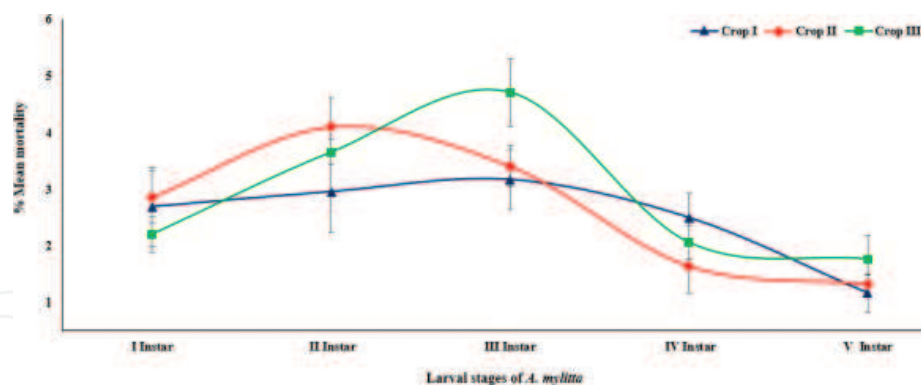
Figure 3. Percent mortality of *A. mylitta* (larva) by *M. brunnea* (source: Gathalkar 2014 [43]).

Figure 4. Predation of *Antheraea mylitta* showing (a) larval attack by *Monomorium minimum* (transporting the first instar larva), (b) *M. destructor* on the cocoon (pupa), and (c) damaged pupa of *A. mylitta* (source: Gathalkar and Barsagade [35]).

for the pollination, predation, scavenging, soil improvement, nutrient cycling, as well as plant dispersal [30, 41, 68]. However, in the Tasar ecosystem, the workers of *Monomorium* species including *M. destructor* and *M. minimum* attack the early larval instars (first to third) of *A. mylitta* (**Figure 4(a)**) besides entering into the cocoon by making holes and feeding on the pupa (**Figure 4(b)** and **(c)**). They attack silkworms during resting and molting on trees, while the pupae, adult, and eggs are primarily affected at grainage.

The ants around households feed on any food available [69]. *Monomorium destructor* is a small ant, which exhibits polymorphism and varies in size from 1.8 to 3.5 mm [70]. These are common household pests, and the foragers are slow in finding food compared with other tramp ants [71]. They are a minor component of the ant fauna with *M. floricola* (Jerdon), *O. smaragdina*, *Crematogaster* sp., and *Paratrechina longicornis* (Latreille) being the most common ants [23]. *Monomorium destructor* forms large polygyne colonies [69], where they form their nest predominantly in trees in hollow twigs and branches and the soil in tropical regions as well [69]. Different foraging patterns employed by the different ant species [72] are in a proportion of foragers whose feeding on liquid food demonstrates high trophallaxis rates [73]. The foraging workers of *Monomorium* sp. are passive movers unlike the erratic foragers from the *Tapinorna* or *Paratrechina* genera [74]. Similarly, *Pheidole* sp. is the major predators of *Alabama argillacea* eggs [75].

In urban populations, ants also cause frequent problems where they destroy the esthetic and other products of human consumption [2, 71]. Occasionally, they also act as vectors of various plant diseases. The attack of some ant species is quite painful to domestic animals as well as human beings [31, 32]. However, these ant species can also be used as an ecological indicator, to assess the ecological status regarding species diversity and the impact of invasive species [76].

2.5.3.1. Behavioral studies

Feeding habits and prey distraction (field invasion): the ants *Monomorium minimum* and *M. destructor* have their terrestrial nests on the Tasar host plants, including *Terminalia tomentosa* and *T. arjuna*, and can be recognized by their conspicuous trail [35]. While foraging, the worker ants attack several larvae of *A. mylitta* as well as pupae, thereby affecting a broad range of host stages (**Figure 4**). Their attack on late instar disturbs the entire spinning process as well as larval development. Due to feeding on the larvae as well as pores made on the cocoon shell, the quality as well as the overall production of raw silk is affected. Some of the ants also carry their prey to their colony. Despite their small size, they are capable of attacking and preying upon much larger larvae of *A. mylitta* (**Figure 4(a)**) (Sup. Info. 3: https://youtu.be/jSycX5tAuMg). During predation, the first instar larva of *A. mylitta* tries to escape many times, but the mandibular grips of *Monomorium* make Tasar larvae attempt to escape futileness [35]. Also, a single ant can also drag the whole first instar larva of the silkworm. Sometimes, they also feed on the late instar larva of *A. mylitta*, which may either be previously damaged by another predator, dead or diseased. Quite often, the damage is severe, and care should be taken during rearing of Tasar silkworm.

2.5.3.2. Damage by Monomorium

The destruction of larvae of the Tasar silkworm by ant predators is severe, and the damage caused to the cocoons due to the pores results in broken silk threads rendering in a loss to the sericulture industry. It also causes a drop in the silkworm population in subsequent generations. The crop-wise mortality is estimated to be between 2 and 4% [18].

2.6. Role of sensory organs in the foraging habits of ants

The antenna of *O. smaragdina* consists of scape, pedicel, and flagellomeres in all castes, with 10 flagellomeres observed in males and 11 in females (workers and queen) [77]. Various types of antennal sensilla have previously been reported in the ants, *Lasius fuliginosus* (Latreille) [78] and *Diacamma* sp. [79, 80]. In *O. smaragdina* (worker), the scape is covered with polygonal cuticular plates (which form the cuticular micro-sculpturing) along with sensilla trichoidea (ST-I and ST-II). In addition, there are three types of sensilla basiconica (SB-I, SB-II, and SB-III) (**Figure 5**). Moreover, STC and ST are present densely on the flagellar segments, while the last two flagellar segments reveal the presence of SB and sensilla ampullacea (SA). The sensilla coeloconica (SC) and SA are intense on the middle surface of the terminal flagellar segments (**Figure 5(k)**). Thus, the presence of these types of sensilla in *O. smaragdina* is similar to sensilla reported in other Hymenopteran species [78–82].
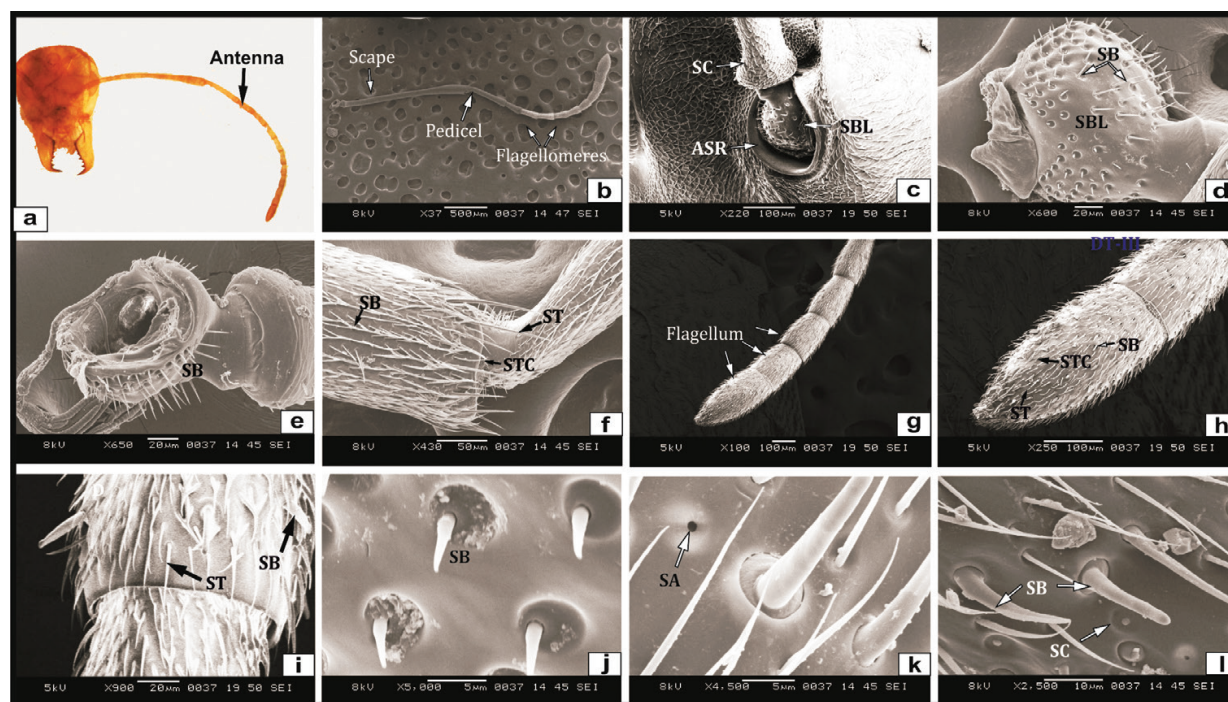
Figure 5. Structure of the antenna of *O. smaragdina* (worker) showing (a) light microscopic view of the head and antenna; SEM micrographs showing (b) the antenna of worker, (c) basal region of antenna, (d) magnified view of scape ball, and (e) scape galina; and magnified view of scape showing shaft base with sensilla, (f) sensilla present on pedicel, (g) funiculus, (h) detailed view funiculus with sensilla, (i) intersegment of the antenna and sensilla, (j) sensilla basiconica, (k) sensilla ampullacea along with basiconica, and (l) basiconica and coeloconica sensilla. *Abbreviations*: SC, scape; SBL, scape ball; ASR, antennal sclerotic ring; ST, sensilla trichoidea; STC, sensilla trichoidea curvata; SB, sensilla basiconica; SC, sensilla coeloconica; and SA, sensilla ampullacea (source: Gathalkar 2014 [43]).

In most of the ant species, the mouthparts are adapted for grasping and feeding on the prey [83, 84]. Paul et al. [85] reported that gustatory sensilla are situated on the lower pair of jaws in the ant. The mandibles in *O. smaragdina* and *M. brunnea* are potent tools for prey catching, fighting, digging, seed crushing, wood-scraping, grooming, brood care, and trophallaxis [2, 86]. There are two types of sensilla trichoidea (ST-I, ST-II) and STC present on the labrum. The ST is on the dorsal surface (DT-I, DT-II, and DT-III in the figure) and on the ventral surface into VT-I and VT-II types (**Figure 6**). The sensilla DT-I is present in the marginal area of the dorsal region of mandibles. The morphology of sensilla in males is similar to that of female except for difference in size (**Figure 6**). On the dorsal side of the mandibles, trichoid sensilla are densely distributed, whereas, on the ventral side, sensilla basiconica predominates. SB is also found in worker mandibles. The labium shows the presence of sensilla ST-I, ST-II, and STC (**Figure 6(m)** and **(n)**). The maxilla is endowed with sensilla trichoidea (ST-I and ST-II) and STC, while the inner surface of maxilla is filled with sensillary fold along with the ST (**Figure 6(o)** and **(p)**). The trichoid sensilla and small peg-like sensilla basiconica on the dorsal and ventral surface of mandibles in dragonfly were reported as mechanoreceptors and chemoreceptors, respectively [87, 88]. Similar sensilla trichoidea and sensilla basiconica observed on the mandible of *C. compressus* [89] and also observed in *O. smaragdina* might be performing a similar function as mechano- and chemoreceptors.
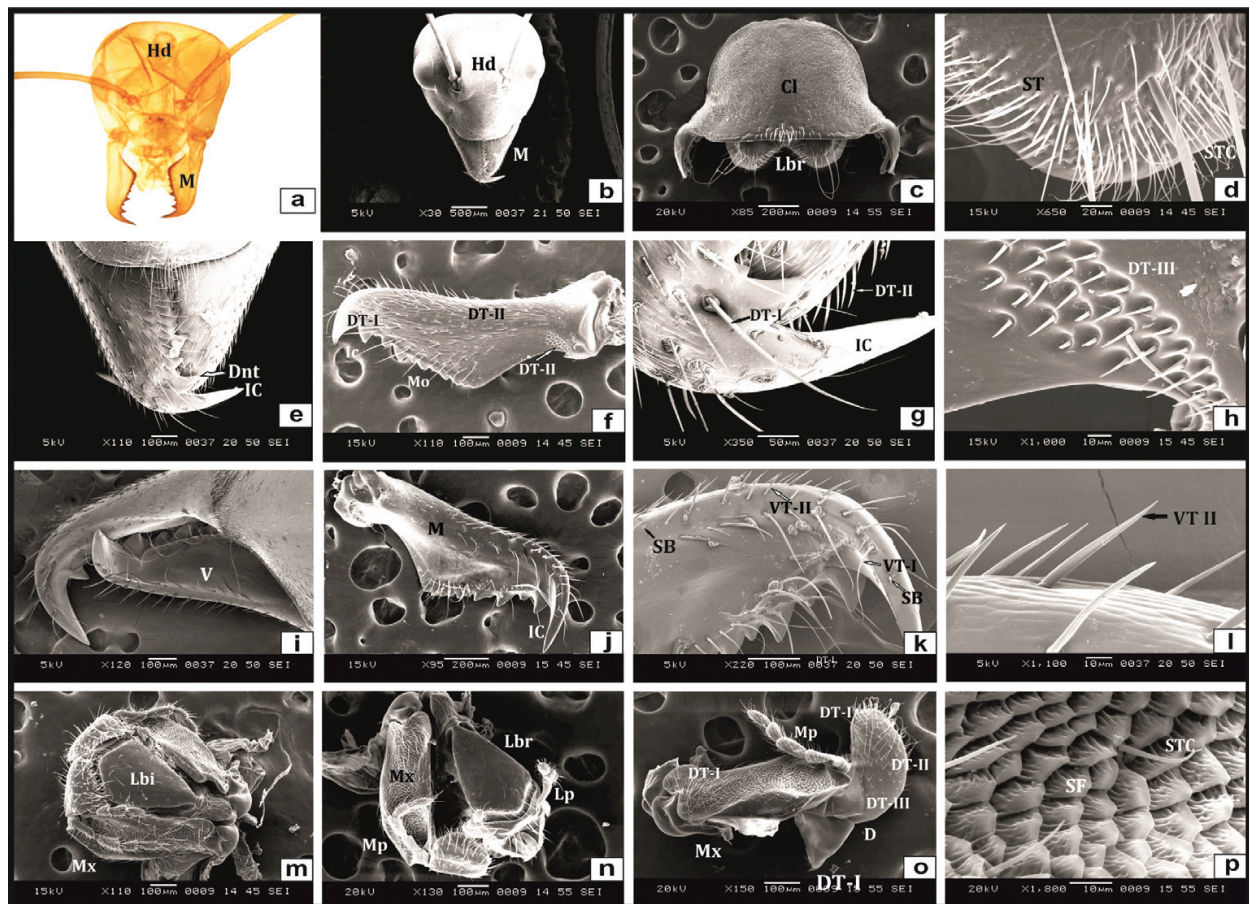
Figure 6. Mouthparts of *Oecophylla smaragdina* (worker) showing (a) light microscopic view of the head with the mandible, SEM view of (b) the head with mouthparts, (c) closed view of the labrum with clypeus, (d) detailed view of the labrum with sensilla, (e) mandible view in detail, (f) the mandible in dorsal view, (g) the mandible with the teeth and sensilla, (h) sensilla trichoidea (DT), (i) closed position of mandibles showing both the dorsal and ventral sides of mandible, (j) the mandible in ventral view, (k) the mandible with the teeth and sensilla; (l) sensilla trichoidea (VT), (m) complex structure of the labium and maxilla; (n) the labium with maxilla and palpi; (o) maxilla with palpi and sensilla, and (p) detailed inner maxillary folds. *Abbreviations*: H, head; M, mandible; cl, clypeus; Lbr, labrum; IC, incisor; MO, molar; D, dorsal side; DT, dorsal trichoid sensilla, Dnt, dentations; Lbi, labium; mx, maxilla; Mp, maxillary palp; SF, sensory folds; V, ventral side; VT, ventral trichoid sensilla (source: Gathalkar 2014 [43]).

Sensilla on the maxillary and labial palpi were characteristically different in their morphology. Sensilla with a bifid curved porous tip suggest a chemosensory function [77]. The present work, therefore, confirms the presence of various types of sensilla on mandibles in worker caste of the ant which play a crucial role in the predatory and feeding behavior of *O. smaragdina*.

The geniculate antenna of *M. brunnea* is elbow shaped, consisting of a scape, pedicel, and five flagellomeres (**Figure 7(a)**) [90]. The scape is covered with polygonal cuticular plates with three types of sensilla basiconica (SB-I, SB-II, and SB-III) (**Figure 7(b)**). The entire surface of the elongated shaft of the scape is also covered with the polygonal cuticular plates as well as sensilla trichoidea ST-I and ST-II. Trichoid sensilla are present throughout the surface of the pedicel in worker ants (**Figure 7(b)**). The flagellum (**Figure 7(c)** and **(d)**)

is covered with sensilla trichoidea curvata (STC) and sensilla trichoidea (ST) and two types of sensilla basiconica. The SC is concentrated on terminal flagellar segments at middorsal position.

Scanning electron micrographs reveal the diversity and density within each of the four basic types of antennal sensilla of *M. brunnea*, namely, the SB, ST, STC, and SC. Similar sensilla were reported on *C. compressus* [91] and other Hymenoptera [78, 79, 81, 82, 92]. Sensilla trichoidea located on the antennae of *M. brunnea* at the pedicel region have also been reported in other species [79, 82]. The SB on the antennae exhibits a similar morphological structure to previously studied ant species and may function as contact gustatory sensilla [80, 82, 93]. The antennal sensilla basiconica (SB) of fire ants, *Solenopsis invicta*, is also known to function as a contact chemoreceptor [94, 95]. Nakanishi et al. [82] categorized two types of trichoid sensilla along with the sensilla trichoidea curvata in *C. japonicus* which does not always respond to
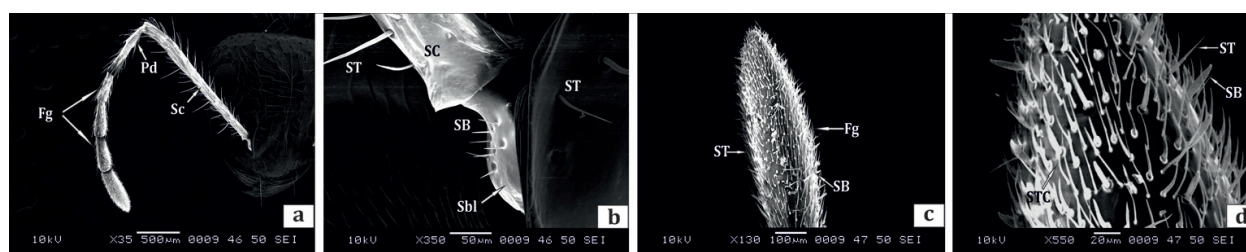

Figure 7. Scanning electron microscopic structure of the antenna of *M. brunnea* showing (a) close view of the antenna with sensilla, (b) antennal socket with ball and scape with sensilla, (c) flagellum, and (d) sensilla present on the tip of the flagellum. *Abbreviations*: Sc, scape; Sbl, scape ball; Fg, flagellum; Pd, pedicel; ST, sensilla trichoidea; STC, sensilla trichoidea curvata; SB, sensilla basiconica (source: Gathalkar and Barsagade [90]).
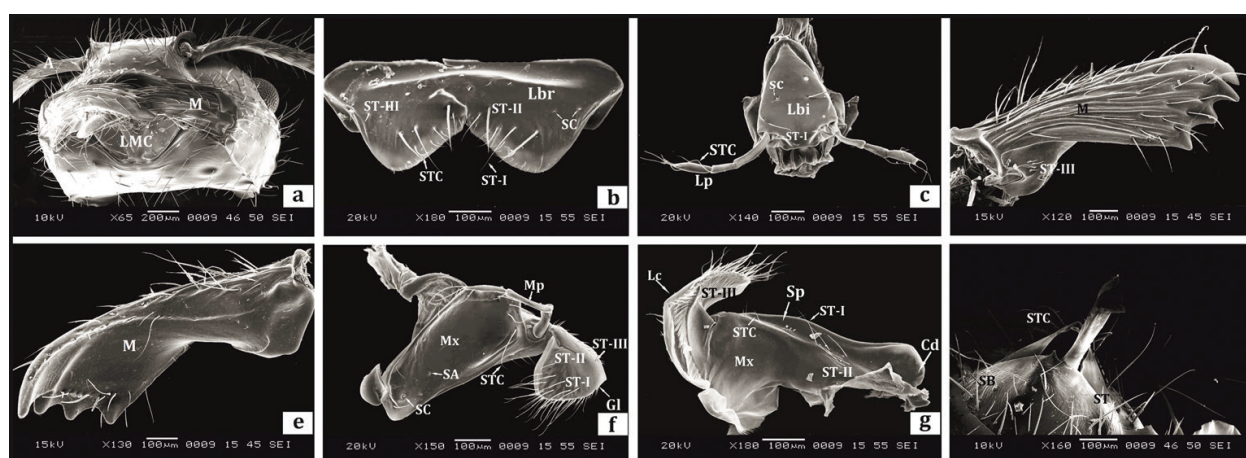

Figure 8. SEM structure of the mouthparts of *M. brunnea*, showing (a) front view of the mouth with arrangements of mouthparts, (b) labrum, (c) labium, (d) dorsal view of the mandible, (e) ventral view of the mandible, (f) dorsal view of the maxilla, (g) ventral view of the mandible, and (h) sting apparatus. *Abbreviations*: A, antenna; Lbr, labrum; Lbi, labium; M, mandible; Mx, maxilla; LMC, labio-maxillary complex; Mp, maxillary palp; Lp, labial palp; cd, cardo; Sp, stipes; Lc, lacinia; Gl, galea; ST, sensilla trichoidea; STC, sensilla trichoidea curvata; SB, sensilla basiconica; SA, sensilla ampullacea; and SC, sensilla coeloconica (source: Gathalkar and Barsagade [90]).

stimulation by alarm pheromones [92, 96]. Thus, these may have a similar function in *M. brunnea* also. The STC in *M. brunnea* resembles those in other ant species [82, 97], which may perform as contact chemosensilla [82, 98].

In *M. brunnea* [90], ultrastructural studies reveal the presence of three types of sensilla, namely, ST, STC, and SC, with three distinct types of trichoid sensilla, namely, ST-I, ST-II, and ST-III (**Figure 8(a–h)**). Additionally, on the labial palp, ST and STC are observed (**Figure 8(c)**). On the mandibles, three types of ST, SB, and SC are observed. The sensilla ST-I is present on the marginal area of the dorsal region of mandibles, while SC is observed on the upper peripheral region (**Figure 8(d)** and **(e)**). In several Myrmicinae, moderately stipulated sting apparatus, which may be spatula shaped as observed in *M. opaciventris*, are well described [99, 100].

During predation, these ants deposit venom into the prey's cuticle by wagging the bent gaster [57].

The furcula, a wishbone-shaped sclerite whose ventral arms are flexible, is attached to the base of the sting, causing the aculeus to pitch, roll, and yaw in probing for a sting site [101].

3. Conclusion

The foraging behavior of various ant species may be harmful or beneficial depending on the host species. In Tasar sericulture, we find ants like *O. smaragdina* and *M. brunnea* which are highly aggressive predators, as well as *Monomorium* sp. With an understanding of the population dynamics of these species, preventive measures can be adopted to prevent losses.

It also helps to develop future pest control strategies to minimize the loss of commercially important crops. The approaches necessary to bring down the losses in Tasar rearing sites due to these predatory ants need to be reevaluated, and in this regard, the possibility of using semichemicals offers a suitable alternative.

Acknowledgements

Conflict of interest

We do not have any conflict of interest.

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