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Morphological and ultra-structural study of Head capsule of Polymorphic forms in *Oecophylla smaragdina* Fabricius (Hymenoptera: Formicidae)

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Abstract
A comparative observation of Head capsule of polymorphic forms in Asian Weaver ants *Oecophylla smaragdina* was carried out to study the functional structural modification in relation with the role of individual in colony propagation and formation. The ultra-structural observation of head sclerite showed clear size variation and demarcation in the fertile and non-fertile members of the colony. Presence of large variation of sensillary structure on the sclerite of Major worker and Drone indicates diverse roles of the individuals in the colony maintenance and propagation.

Keywords: Ants, sensilla, Weaver ants, SEM

Introduction
Oecophylla smaragdina is a social Hymenopteran ant also known as Asian Weaver ant. Greenslade (1972) [13], reported about the distribution of Asian weaver ant in Oriental region from India to Queensland and Solomon Islands. Social structure of the colony consists of fertile and infertile castes. The fertile caste comprises of Drone (male) and Queen (female) whereas the infertile caste is of workers. According to Vanderplank (1960) [36], fertile caste of *Oecophylla longinoda*, another species of weaver ants do not require nuptial flight as they mate inside the nest; whereas Peng *et al*., (2013) [39], reported nuptial flight in *O. smaragdina.* Bolton (1994) [3], stated weaver ant life cycle comprise of four stages i.e. of egg, larva, pupa and adult in the hive and duration of development from egg to adult in weaver ant, *O. smaragdina* is approximately 30 days, three larval instars with a naked pupal period in period in other species of weaver ant *O. longinoda*. Bharti and Kaur (2011) [2], reported three instars in *O. smaragdina*.
Hölldobler and Wilson (1983) [15], reported about two different types of worker which have distinct responsibilities to perform in the colony; workers show a clear size distribution between minor and major workers. There is a division of labour associated with the size difference between workers. Workers perform tasks that are essential to colony survival including foraging, nest construction and colony defense. The exchange of information is facilitated by the use of chemical and tactile communication signals. Pheromone trails are also used by workers who also have a responsibility of safeguarding the nest and are called as patrollers to recruit workers against territorial intruders. Along with chemical signals, workers also use tactile communication signals such as attention and body shaking to stimulate activity in signal recipients. Multimodal communication in *O. smaragdina* weaver ants importantly contribute to self-organization (Hölldobler and Wilson, 1977) [1].
So the present work was carried out to study the morphological and ultrastructural variation in the Head capsule of adult polymorphs in *O. smaragdina* and various sensillae related to distribution of labour in the colony.

Materials and Methods
Insect sources
Oecophylla smaragdina colonies were collected from the fruit orchards in Central and Western India. The collected nest was kept in fridge at -10 ºC in a plastic container for 15 minutes to make the worker ants inactive. The nest was opened up with the help of forceps and various stages of life cycle were collected and preserved in 70% alcohol for further studies.

Morphological preparation
For external morphology freshly preserved specimen treated with 10% KOH (60 ºC) for 20 min. Dissections were carried out under a stereoscopic binocular microscope Olympus SZX7, head was separated and washed several times in the water and later dehydrated by passing through ascending grades of alcohol, cleared in xylene, and mounted in DPX.

Scanning Electron Microscopy
For scanning electron microscopic (SEM) study. The dissected head was washed thoroughly with distilled water and fixed in 10% formalin for 12 hrs. The specimens were then dehydrated in ascending series of alcohol grades, cleared in acetone and dried at room temperature. After that, the head was mounted on carbon-coated metallic stubs at different angles followed by platinum coating in JOEL coating unit. Specimens observed with a JOEL JSM- 7600 F SEM at 25-5500 X magnification at the Sophisticated Analytical Instrumentation Facility (SAIF) of Indian Institute of Technology (IIT) Mumbai, India.

Statistical Analysis
The data generated during observation was compiled and analysed using simple measures of central tendency. The mean, standard deviation and ±standard error was calculated, by using Microsoft Excel 2007 software package. All statistics presented in this study are mean ±standard error, Student 't' test made use for testing significance of difference between the means of reading of experimental and control group using 5 percent level of significance.

Results
Structure of head surface in polymorphic forms of *Oecophylla smaragdina*
Minor Worker
The head of minor worker was triangular & pointed towards the anterior and broader towards the posterior region. The head measured about 1.19±0.14 mm in length and 1.10±0.11 mm in width. Well-developed compound eyes were present laterally to the head capsule. Pair of tentorial pits is found on epistomal suture postero-lateral to the clypeus. A pair of geniculate antenna was present posterior to the clypeus at the frontal sclerites, attached to the head capsule with antennal suture. The antenna consists of three segments known as scape, pedicel and flagellum. The anterior part of head capsule shows presence of well-developed typical biting and chewing mouth parts, comprising of a labrum, a pair of mandibles and a labio- maxillary complex (Fig. 3**).**

Major Worker
The head of major worker was triangular with narrow anterior end and broad posterior part measured about 2.07±0.07 mm in length and 1.60±0.29 mm in width around the frontal region. The appendages are like that minor worker except in size. A pair of well-developed compound eyes was present laterally on the head. The tentorial pits present in the epistomal suture postero-lateral to the clypeus. A pair of geniculate antennae was present in the frontal region attached to the head with the antennal suture. A well-developed biting and chewing type of mouth-parts were present in the anterior part of head capsules. The mouthpart comprised of a pair of big serrated mandibles with anterior labrum and a ventral labial complex (Fig. 4).

Drone
The head was highly sclerotized with prominent compound eyes present postero-laterally to the frontal sclerites and measured about 1.00±0.59 mm in length and 1.30±0.23 mm in width at the mid region. Prominent median ocelli on the frontal plate and a pair of lateral ocelli were present on the anterior vertex plate. The postero-lateral frontal sclerites show presence of antennal suture with geniculate antenna. The median ocellus was bigger than the lateral ocellus. The epistomal suture shows presence of a pair of tentorial pits posterior to clypeus. The mouth parts were vestigial with a weak non-serrated pair of mandibles without dentition, dorsal labrum, and ventral labium complex (Fig.5**).**

Queen
The head size was biggest among all polymorphic castes and measured about 3.10±0.07 mm in length and 2.92±0.06 mm in width at the mid region. The prominent median ocellus on the frontal plate and a pair of lateral ocelli presents on the anterior vertex plate of head. The size of median ocellus was bigger than the pair of lateral ocelli. The antennae were well developed. The mouthparts were biting and chewing type with strong serrated pair of mandibles and broad plate like dorsal labrum with a ventral labial complex. A pair of well-developed tentorial pits present in the epistomal suture, postero-lateral to the clypeus. (Fig.6).

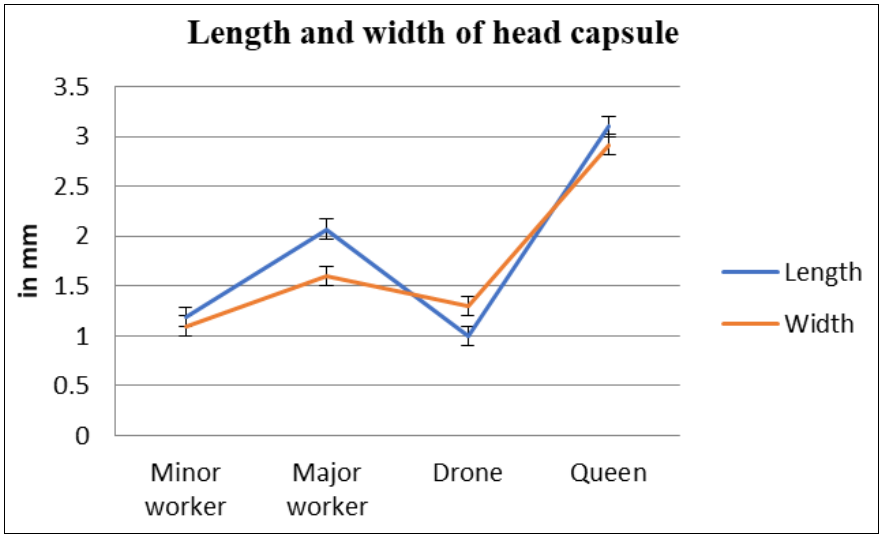

Fig 1: Length and width of head capsule in polymorphic forms of *O.smaragdina*.

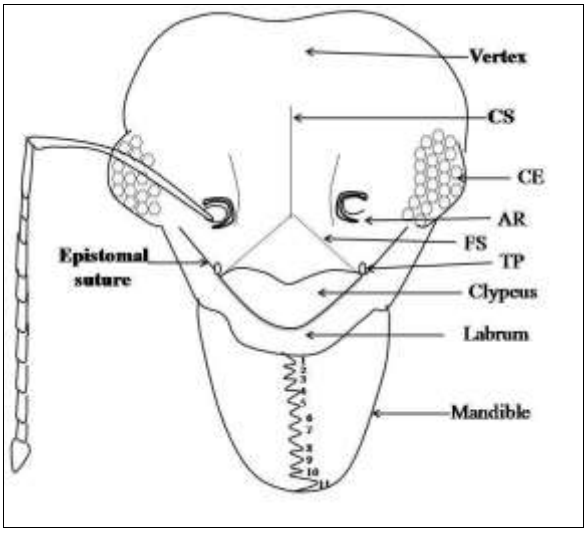

Fig 2a

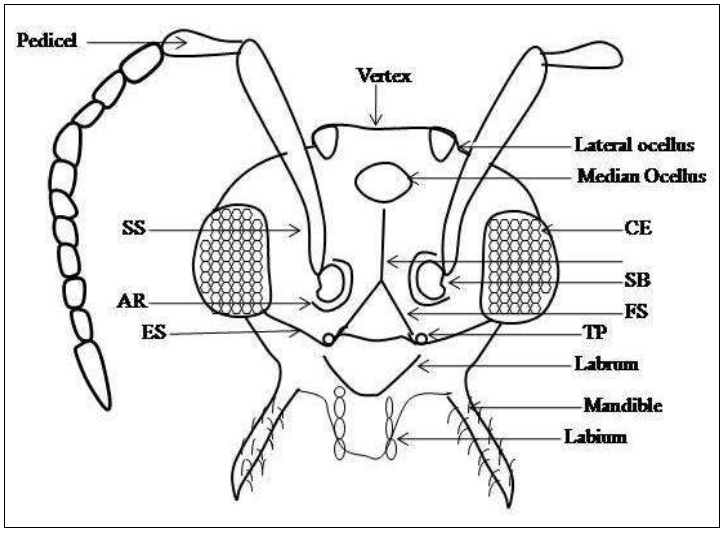

Fig 2b

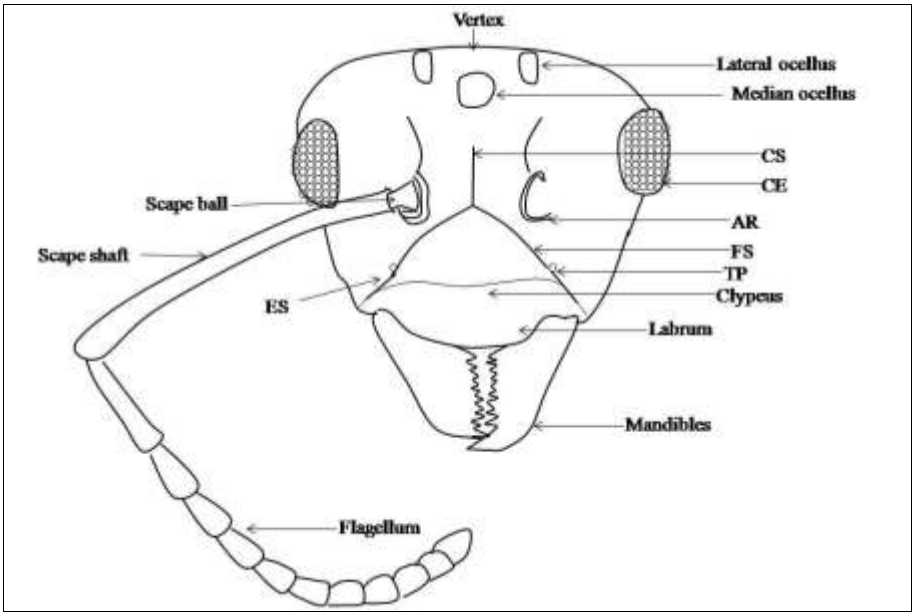

Fig 2c

Fig 2a: Diagrammatic Worker, 2 b. Drone, 2 c. Queen.

Table 1: Length and width of head capsule in adult individual of different caste in *O. smaragdina*

Castes	Total length of the body	Head		Size of Ocellus	
	Length (mm)	Length (mm)	Width (mm)	Median	Lateral
Minor worker	5.33±0.43	1.19±0.14	1.10±0.11	-	-
Major worker	9.00±0.70	2.07±0.07	1.60±0.29	-	-
Drone	7.31±0.32	1.00±0.59	1.30±0.23	139.13 µm	137.14 µm
Queen	15.71±0.38	3.10±0.07	2.92±0.06	360 µm	354 µm

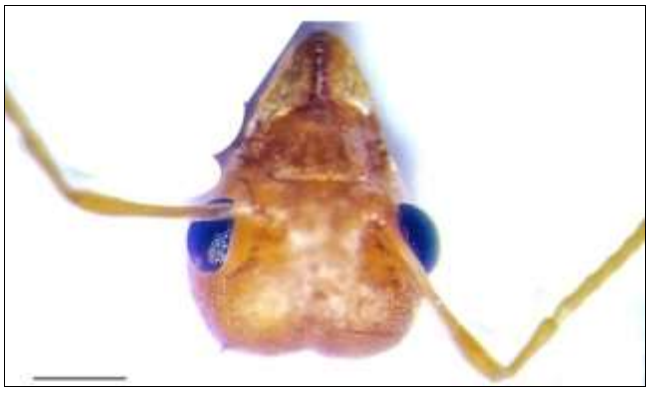

Fig 3: Dorsal view of head capsule of Minor Worker

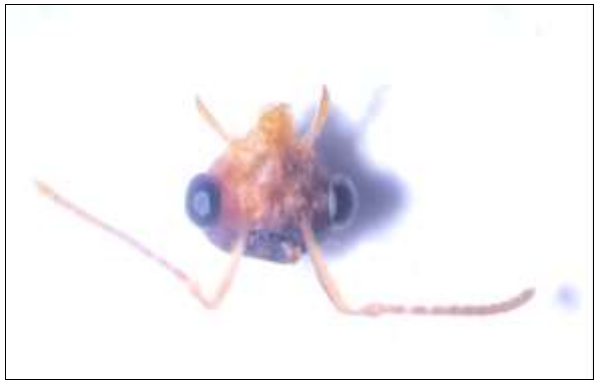

Fig 4: Dorsal view of head capsule of Major Worker

Fig 5: Dorsal view of head capsule of Drone (Male)

Fig 6: Dorsal view of head capsule of Queen (Fertile Female)

Abbrv. CE-Compound Eyes, AR-Antennal ring, FS-Frontal suture, CS- Cranial suture, TP- Tentoral pit, ES- Epistomal suture.

Dorsal view of Polymorphic forms of *Oecophylla smaragdina*

Scanning Electron Microscopy of head capsule: Head capsules of polymorphic forms in *O. smaragdina* shows the sensilla trichodea present on the minor and major workers on dorsal and ventral side of head, while the drone and queen show presence of three different types of sensilla *viz*. sensilla trichoidea, sensilla trichodea curvata and sensilla basiconica. **(**Table. 2**)**

Ultra-structure of head capsule of minor and major workers. The scanning electron microscopic observation of head capsule of minor worker reveals the presence of sensilla trichodea on the head sclerites. Sensilla trichoidea were observed in numerous, scattered form throughout the dorsal surface of the head cuticle. The surface of the sensilla was smooth arising from a swollen basal area and pointed towards the apex. The sensilla measured about 19.04±1.50 µm and 9.09±0.05 µm in length and width in minor worker, while it measured about 16.07±0.65 µm and 1.42±0.01 µm in length and width at the base respectively in major worker (Fig.7 & Fig.8)

Ultra-structure of head capsule of Drone. : The scanning electron microscopic observation of head capsule of drone reveals the presence of two types of sensilla on the head sclerites, as sensilla trichodea and sensilla trichodea curvata. (Fig.9)

Sensillae Trichoidea: Sensilla trichoidea is observed in scattered on the vertex. These are broad at the base and pointed towards the apex. The sensilla are measured about 26.17±2.10 µm in length and 3.19±0.20 µm in width respectively.

Sensillae Trichoidea Curvata: Sensilla trichoidea curvata running parallel to the coronal suture are observed from the frons region to the vertex region on head. There are six to seven pairs of sensilla observed anterior to posterior end on dorsal region of the head. The surface of the sensilla is smooth, slightly curved with tapered end. The shaft of sensilla arises from a well-developed socket project from a double ring circular base. The sensilla are measured about 17.22±0.90 µm while 1.47±0.06 µm in length and width respectively.

Ultra-structure of head capsule of Queen. : The scanning electron microscopic observation of head capsule of queen reveals the presence of sensilla trichodea and sensilla basiconica on the head sclerites. (Fig.10)

Sensillae Trichoidea: Sensilla trichoidea are observed in numerous, scattered form throughout the dorsal surface of the head cuticle. The surface of the sensilla is smooth arise from a swollen basal area and pointed towards the apex. The sensilla are measured about 45.5±2.53 µm and 1.47±0.06 µm in length and width at the base respectively.

Sensillae Basiconica: Present near the antennal socket, encircling the antennal ridge completely. This is small peg like sensilla measuring about 16.84±0.76 µm and 3.12±0.03 µm in length and width at the base respectively.

Discussion

According Hölldobler and Wilson (1990) [17], the variation in size is common in ants. In other eusocial insects various polymorphic forms has been noticed by earlier workers (Noirot & Pasteels, 1987, Hölldobler and Wilson, 2009, Kövacs *et al*., 2010, Gruter *et al*., 2012, Sautheir *et al*., 2017) [24, 40, 41, 14, 34]. Noirot and Pasteels, (1987) [24] has noted size variation in termites, in stingless bees (Gruter *et al*. 2012) [14], social vasps (Kövacs *et al*., 2010) [41], and in honeybees. During the present study it has been observed that body size varies in polymorphs of *O. smaragdina* colony where, the minor worker was smallest followed by the drone in terms of size dimension. The major worker was bigger in size than the minor worker and drone. The queen of *O. smaragdina* was observed as, the biggest in size and dimension amongst the all members of colony.

According to Wheeler (1971) [37], the morphological differences in social hymenopteran are a result of different roles played by individual in the colony. Earlier caste dimorphic studies on many social hymenopterans have been carried out by various workers (Kövacs *et al*., 2010) [41]. During the present study it has been observed that in eusocial arboreal ant *O. smaragdina*, social behavior and colony propagation were found in one and the same colony, while the different polymorphs like minor worker, major worker, drone, and queen were morphologically different from each other. According to Beutel and Pohl (2007) [28], hymenopteran heads have orthognathy or hypognathic ground plan, while Bolton *et al*., (1994) [3], observed functional prognathous head

orientation in hymenopteran worker caste. During the present study it has been observed that the fertile caste (Queen and Drone) shows presence of hypognathous orientation of head whereas, the minor and major workers have a working prognathous orientation of head capsule and mouthparts were parallel to the body axis. Chapman (1998) [6], also explained prognathous orientation of head is correlated to predaceous food habit of the insect, Peng *et al*., (2005) [27], has confirmed predatory behavior of *Oecophylla smaragdina* workers. During the present observation both minor and major worker were found as predator in nature.

According to Snodgrass (1935) [31], the limits between the head sclerites become uncertain when the sutures are not clearly visible, Saini and Dhillon (1981) [32], studied various hymenopteran families and confirmed incomplete or completely absent epicranial sutures on the cranium. Beutel and Pohl (2005) [29], found absence of epicranial suture in Hymenoptera family, Strepsiptera. In the present study, faint inverted Y shaped epicranial sutures in drone and queen were observed, The Y suture later on divided into single median dorsal coronal suture and a pair of anterior frontal suture towards the mouthpart making weak separation of head sclerites. Whereas in minor and major worker of *O. smaragdina* the epicranial sutures was completely absent. Snodgrass (1935) [31], found that the frontal suture continues anteriorly as epistomal suture with pit like opening of tentorial arms dividing the frontal sclerite into dorsal frons and anterior clypeus of all pterygote insects. Erickson and Sheng (1983) [11], confirmed presence of an epistomal suture in honeybees and an associated opening of anterior tentorial pits. Duporte and Bigelow (1957) [8], observed the anterior tentorial pits at the junction of frontocypeal suture and clypogenal suture in Hymenoptera. Confirmed presence of tentorial pit at the epistomal suture in sawfly, while Klass and Eulitz (2007) [20], observed anterior tentorial pits in Dictyoptera. In the present study a pair of anterior tentorial pits was observed at the epistomal suture on the junction of clypogenal suture in all polymorphs of *O. smaragdina*, and supported the observation of earlier workers.

Snodgrass (1935) [31], described general structure of insect head including dorsal and lateral ocelli on the vertex as one of the photo sensory organs, and the position of the ocelli is according to the facial area of the insect head. Böhm and Pass (2016) [4], described the location of lateral ocelli in Archaeognatha beneath the compound eyes, which is an exception from typical insect ocelli in field view and shape. In the present study on polymorphic forms of *O. smaragdina* the position of dorsal and lateral ocelli was observed on dorsal surface of the head at the vertex following typical hexapod ground plan of ocelli position. It was further noticed that the size of median and lateral ocelli varies in drone and queen of *O. smaragdina* in relation to the shape and size of the head capsule.

Kalmus (1945) [18-19], described the structural correlation of wings and ocelli during flight mechanism in flying insects, observed the role of dorsal and lateral ocelli in photoreception along with compound eyes. In *O. smaragdina* the presence of head sensory organs confirmed their role in vision during flight performed neurological study on locust sense organ and confirmed innervations of light sensitive l-neurons in the ocelli enhancing light sensitivity than the compound eyes, and ocelli increased range of vision up to 140º in flying insects. Taylor (1980) [42], confirmed the role of ocelli in flight orientation with respect to light in locust. Recently, Dickinson (2015), observed the role of dorsal ocelli in dragonfly for preying. Presence of well-developed ocelli on the head sclerite in fertile members of colony indicates significance of ocelli in flights action with increased range of vision and adaptability to low light for nuptial flights in fertile caste of *O. smaragdina* as noted in another social hymenopteran. The fertile members of Hymenoptera were observed with well-developed wings and dorsal ocelli during emergence used for nuptial flight during night (Hölldobler and Wilson, 1990) [17]. Whereas, the minor worker and major worker were observed to be devoid of any flying organs as well as any ocelli on the head sclerites. It could be possible that the loss of sense organs in the worker ants as it has no use (Hölldobler and Wilson, 1990) [17].

A pair of well-developed compound eyes present dorso-laterally on the head capsule was observed in all the polymorphs of *O. smaragdina*. According to Land and Nelson (2009) [23], apposition compound eyes are the prominent eye design in most diurnal insects including Hymenoptera. Somanathan *et al*., (2009) [33], studied behavior of diurnal activity in carpenter bees in relation to apposition compound eyes. Narendra *et al*. (2011) [25], studied four different species of *Mrymecia* ants and confirmed caste specific differentiation of compound eyes in all the four species with relation to daily activity. In the present study it has been observed that the foraging minor and major workers were found with well-developed apposition compound eyes, whereas the drone and queen even if not participated in foraging activity also has well developed compound eyes confirming their diurnal activity outside the hive and it may be important during mating season.

Autrum and Stumpf (1950) [43], first reported presence of sensilla trichodea on the head of social ants *Mrymica rubra*, *Lasius niger*, *L. fuliginous* and *Formica rufa*. Dey (1998) [44], reported and classified various other sensilla including sensilla trichodea in worker of *Tetraponera rufonigra*. The described role of sensilla in identification of nest mate and non-nest mate in ants for colony propagation was described by Ozaki *et al*. (2005) [45]. Crozier *et al*. (2010) [7], confirmed the use of sensillae to detect chemical signals to identify nest mate and non-nest mate in the ant colony. Kadu (2009) [22], confirmed presence of sensilla trichodea on the head capsule of polymorphs in *Camponotus compressus*. During the present, ultra-structural observation of head sclerites in polymorphs of *O. smaragdina* shows presence of sensilla trichodea on dorsal ant ventral surface of the head capsule classified into, Sensilla trichodea and sensilla trichodea curvata. On the head capsule of *O. smaragdina* queen presence of sensilla basiconica has been observed. Faucheux (1991) [12], reported presence of sensilla trichodea, sensilla trichodea curvata and sensilla basiconica, and their numbers on cephalic appendages is a character of sexual dimorphism in Lepidoptera as sensilla basiconica was reported in higher numbers in females. Zhang *et al*. (2013) [38], reported the significant difference between distribution of cephalic sensillae in male and female of coleopteran beetle *Chrysolina aeruginosa*. Recently Zhang *et al*. (2016) [46], reported difference in number and distribution of sensillae in both sexes of coleopteran *Coboldia fuscipes*. In the present study, the distribution of sensilla trichodea and sensilla basiconica was seems to be caste specific as sensilla basiconica was observed only on queen head sclerite of *O. smaragdina*. According to Hashimoto (1990) [16] and Ramirez *et al*. (2017) [30], sensilla trichodea functions as a chemoreceptor whereas

sensilla basiconica functions as tactile chemoreceptor. The presence of sensilla trichodea on dorsal surface of head capsule in polymorphs of *O. smaragdina* may use in chemical communication while, presence of sensilla basiconica only on the head capsule of queen may have a role in tactile communication. According to Dumpert (1972) [9], sensilla trichodea curvata is sensitive to various volatile compound including alarm pheromones. The presence of sensilla trichodea curvata on the dorsal surface of head capsule in drone of *O. smaragdina* may have a role in chemical communication or may be used during searching of female during mating season.

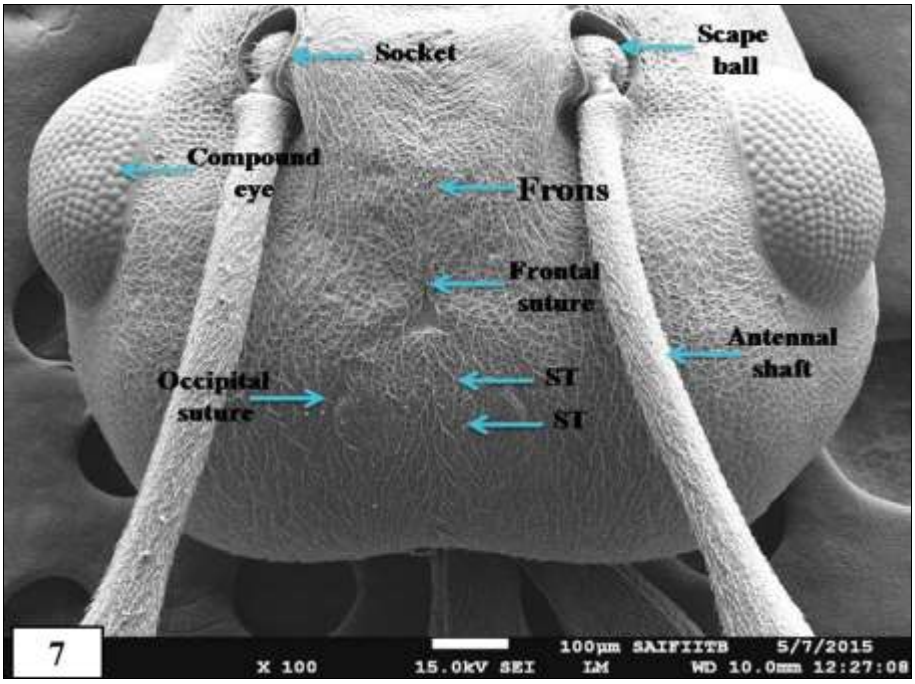

Fig 7: SEM photomicrograph of dorsal surface of minor worker showing sensilla trichodea ST on the head sclerite.

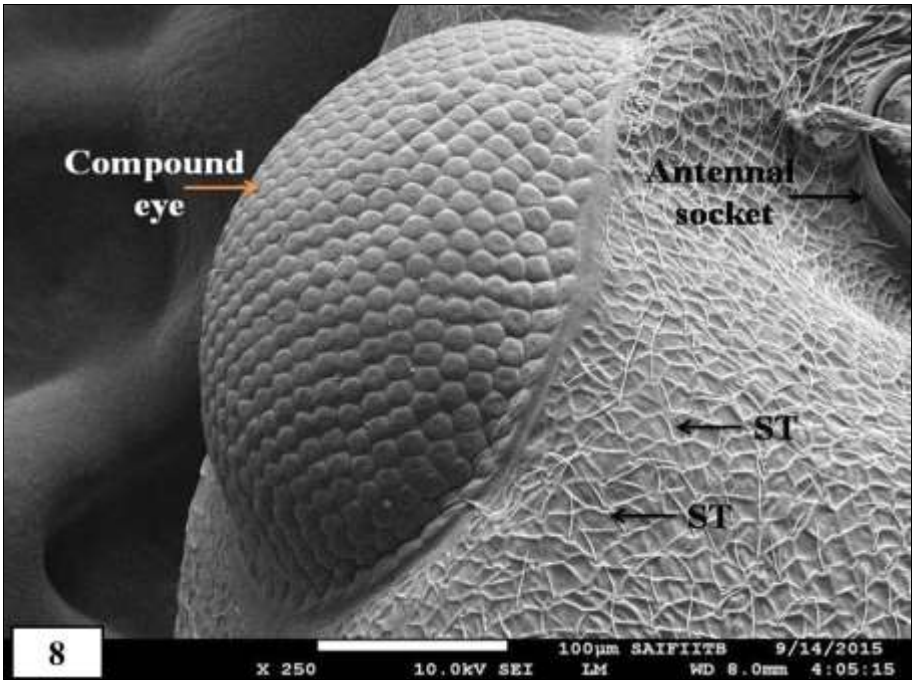

Fig 8: SEM photomicrograph of dorsal surface of major worker showing sensilla trichodea ST on the head sclerite.

Fig 7-8: SEM photomicrograph of head capsule of minor and major worker of *O.smaragdina* showing various type of sensilla. Abbrv: ST-sensilla trichodea, SB-sensilla basiconica, STC-sensilla trichodea curvata.

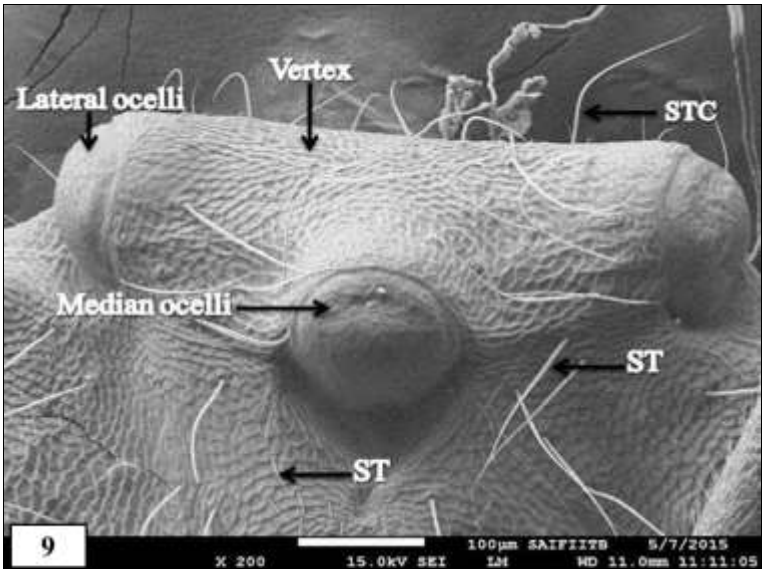

Fig 9: SEM photomicrograph of dorsal surface of minor worker showing sensilla trichodea ST and sensilla trichodea curvata STC on the head sclerite.

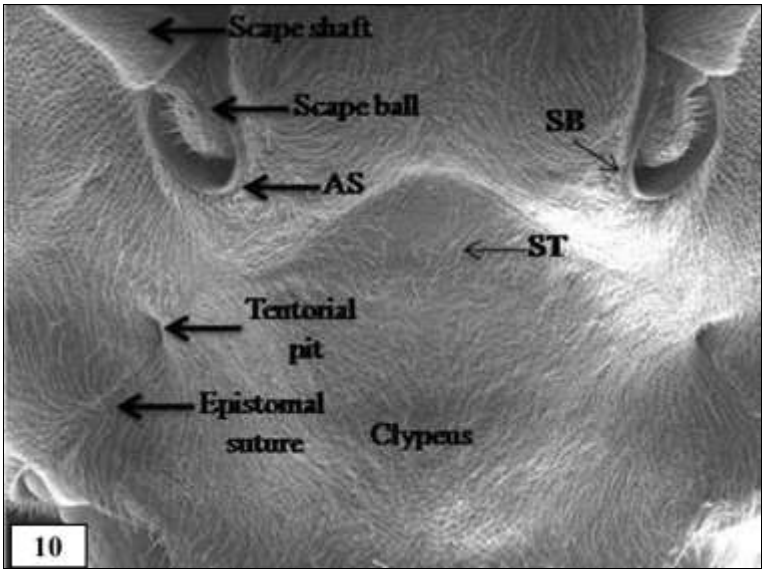

Fig 10: SEM photomicrograph of dorsal surface of queen showing sensilla trichodea ST and sensilla basiconica SB on the head sclerite.

Fig 9-10: SEM photomicrograph of head capsule of drone and queen of *O. smaragdina* showing various type of sensilla.
Abbrv: ST-sensilla trichodea, SB-sensilla basiconica, STC-sensilla Trichodea curvata

Table 2: Length and width dimension of sensillae present on head capsule of various caste of *O. smaragdina.* (Values are mean± standard deviation)

Caste	Types of sensillae								
	ST			STC			SB		
Minor Worker	ST			--			--		
	Length (µm)	Width (µm)							
		Apex	base						
	19.04±1.50	4.76±0.01	9.09±0.05						
Major Worker	ST			--			--		
	Length (µm)	Width (µm)							
		Apex	base						
	16.07±0.65	0.71±0.01	1.42±0.01						
Drone	ST			STC			--		
	Length (µm)	Width (µm)		Length (µm)	Width (µm)				
		Apex	base		Apex	Base			
	29.19±2.10	1.25±0.02	3.19±0.20	17.22±0.90	0.95±0.05	1.47±0.06			
Queen	ST			--			SB		
	Length (µm)	Width (µm)					Length (µm)	Width (µm)	
		Apex	base					Apex	base
	45.55±2.53	0.95±0.05	1.47±0.06				16.84±0.76	3.12±0.03	3.12±0.03

Conclusion

As per the above observation it may be concluded that Polymorphs of *O. smaragdina* show variation in morphometric dimension of head capsule, the queen has largest head. The head in polymorphs of *O. smaragdina* is hypognathous and triangular. The fertile caste (drone and queen) adults head capsules have prominent median and lateral ocelli, whereas in minor and major worker head capsule is devoid of ocelli.

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References

1. Bert Holldobler, Edward Wilson. Weaver Ants: Social Establishment and Maintenance of Territory science. 1977;195(4281):900-902.
2. Bharti H, Silla S. Notes on Life history of *Oecophylla smaragdina* (Fabricius) and its potential as biological control agent. Halter. 2011;3:59-64.
3. Bolton B. Identification Guide to the Ant Genera of the World. Journal of Entomology. 1994;101:203-208.
4. Böhm Alexander, Günther Pass. The ocelli of Archaeognatha (Hexapoda): functional morphology, pigment migration and chemical nature of the reflective tapetum. Journal of Experimental Biology. 2016;219(19):3039-3048.
5. Cesare Baron Urbani, Barry Bolton, Philip S Ward. The internal phylogeny of ants (Hymenoptera: Formicidae) Systematic Entomology. 1992;17(4):301 -329.
6. Chapman RF. The Insect structure and function. Cambridge University press; c1998.
7. Crozier Ross H, Philip Newey S, Ellen Schlüns A, Simon Robson KA. A masterpiece of evolution – *Oecophylla* weaver ants (Hymenoptera: Formicidae). Myrmecol News. 2010;13(5):57-71.
8. Duporte Melville E. The comparative morphology of the insect head. Annu. Rev. Entomol. 1957;2(1):55-70.
9. Dumpert K. Alarm receptor on the antenna of *Lasius fuliginosus* (Latr.) (Hymenoptera, Formicidae). Journal of comparative physiology. 1972;76(4):403-425.
10. Dickinson Michael H. Motor Control: How Dragonflies Catch Their Prey Current Biology. 2015;25(6):R232-R234.
11. Erickson EH, Jr, Sheng H. Structure of the Honeybee Tentorium. Journal of Apicultural Research. 1984;23(4):181-188.
12. Faucheux Michel J. Morphology and distribution of sensilla on the cephalic appendages, tarsi and ovipositor of theeuropean sunflower moth, *Homoeosoma nebulella* den. & Schiff. (Lepidoptera: Pyralidae). Int. I. Insect Morphol. & Embryol. 1991;20(6):291-307.
13. Greenslade PJM. Comparative ecology of four tropical ant species. Insectes Sociaux. 1972;19(3):195-212.
14. Grüter C, Menezes C, Imperatriz-Fonseca VL, Ratnieks FL. A morphologically specialized soldier caste improves colony defense in a neotropical eusocial bee. Proceedings of the National Academy of Sciences. 2012 Jan 24;109(4):1182-1186.
15. Hölldobler B, Wilson EO. Queen control in colonies of weaver ants (Hymenoptera: Formicidae). Ann. Entomol. Soc. Am. 1983;76(2):235-238.
16. Hashimoto Y. Unique Features of Sensilla on the Antennae of Formicidae (Hymenoptera). Appl. Ent. Zool. 1990;25(4):491-50.
17. Hölldobler B, Wilson EO. The Ants. Belknap Press of Harvard University Press Cambridge, MA, 1990, 732.
18. Kalmus H. Correlations bettween flight and vision, and particularly between wings and ocelli, in insects. PROC. R.ENT. SOC. LOND. (A). 1945;20:84-96.
19. Kalmus H. Correlations bettween flight and vision, and particularly between wings and ocelli, in insects. PROC. R.ENT. SOC. LOND. (A). 1945;20:84-96.
20. Klass Klaus-Dieter, Eulitz UTE. The tentorium and anterior head sulci in Dictyoptera and Mantophasmatodea (Insecta). Zoologischer Anzeiger. 2007;246(3):205–234.
21. Krapp HG, Wicklein M. Vision-I. In The Senses: A Comprehensive Reference. Academic Press; c2008.
22. Kadu SG. Biology and bioinsecticidal control of the Carpenter ant, *Camponotus compressus* Fabricius (Hymenoptera: Formicidae) Ph.D. Thesis submitted to Nagpur University; c2009.
23. Land, Michael F. Eyes and Vision. Chapter 96. Encyclopedia of Insects (Second Edition). Academic Press; c2009.
24. Noirot C, Pasteels JM. Ontogenetic development and evolution of the worker caste in termites. Experientia. 1987;4(8):851-952.
25. Narendra Ajay, Samuel Reid F, Birgit Greiner, Richard Peters A, Jan Hemmi M, Willi Ribi A, *et al*. Caste-specific visual adaptations to distinct daily activity schedules in Australian Myrmecia ants. Proc. R. Soc. B. 2011;278(1709):1141–1149.
26. Peng RK, Christian K, Gibb K. Locating queen ant nests in the green ant, *Oecophylla smaragdina* (Hymenoptera: Formicidae) Insectes soc. 1998;45:477- 480.
27. Peng RK, Christian K. The control efficacy of the weaver ant, *Oecophylla smaragdina* (Hymenoptera: Formicidae), on the mango leafhopper, *Idioscopus nitidulus* (Hemiptera: Cicadellidea) in mango orchards in the Northern Territory. International Journal of Pest Management. 2005;51(4):297-304.
28. Rolf Georg Beutela, Lars Vilhelmsen. Head anatomy of Xyelidae (Hexapoda: Hymenoptera) and phylogenetic implications organisms. Diversity & Evolution. 2007;7(3):207-230.
29. Rolf Georg Beutela, Lars Vilhelmsen. Head anatomy of Xyelidae (Hexapoda: Hymenoptera) and phylogenetic implications organisms. Diversity & Evolution. 2007;7(3):207-230.
30. Ramirez-Esquivel F, *et al*. The sensory arrays of the ant,. *Temnothorax rugatulus*, Arthropod Structure & Development; c2017. http://dx.doi.org/ 10.1016/j.asd.2017.03.005.
31. Snodgrass RE. The anatomy of the honeybee. Technical series, no. 18. Washington: government printing office; c1910.
32. Saini Malkiat S, Dhillon Surjit S. Evolutionary Changes in the Symphytan Cranium Pertaining to Epicranial and Paroccipital Sutures (Hymenoptera). Journal of The Kansas Entomological Society. 1981;54(3):458-464.
33. Somanathan Hema, Kelber Almut, Renee Borges M, Rita Wallen, Eric Warrant J. Visual ecology of Indian carpenter bees II: adaptations of eyes and ocelli to nocturnal and diurnal lifestyles. J Comp Physiol A. 2009;195:571-583.

34. Sauthier Romain, Price Robbie I'anson Grüter, Christoph. Worker size in honeybees and its relationship with season and foraging distance. Apidologie. 2017;48:234-246.
35. Taylor Charles P. Contribution of compound eyes and ocelli to steering of Locusts in flight J. exp. Biol. 1981;93(1):1-18.
36. Vanderplank FL. The bionomics and ecology of the red tree ant, *Oecophylla* sp. and its relationship to the coconut bug *Pseudotheraptus wayi* Brown (Coreidae). Journal of Animal Ecology. 1960;29:15-33.
37. Wheeler GC, Wheeler J. Ant larvae of subfamily Ponerinae: second supplement. Annals of the Entomological Society of America. 1971;64(6):1197-1217.
38. Zhang LU, Li-Li Ren, You-Qing Luo, Shi-Xiang Zong. Scanning Electron Microscopy Analysis of the Cephalic Sensilla of *Chrysolina aeruginosa* Fald. (Coleoptera: Chrysomelidae). Microscopy Research and Technique. 2013;76(4):423–431.
39. Peng G, Meier WN, Scott DJ, Savoie MH. A long-term and reproducible passive microwave sea ice concentration data record for climate studies and monitoring. Earth System Science Data. 2013 Oct 15;5(2):311-8.
40. Holldobler B, Wilson EO. The superorganism: The beauty elegance and strangeness of insect societies. WW Norton & Company; c2009.
41. Kovács ÁM, Téglás E, Endress AD. The social sense: Susceptibility to others' beliefs in human infants and adults. Science. 2010 Dec 24;330(6012):1830-4.
42. Taylor JB. Aggregate dynamics and staggered contracts. Journal of political economy. 1980 Feb 1;88(1):1-23.
43. Autrum H, Stumpf H. The bee's eye as an analyzer of polarized light. Z. Naturforsch. 1950;5:116.
44. Dey A, Spinrad H, Stern D, Graham JR, Chaffee FH. A Galaxy at z= 5.34. The Astrophysical Journal. 1998 May 1;498(2):L93.
45. Ozaki M, Wada-Katsumata A, Fujikawa K, Iwasaki M, Yokohari F, Satoji Y, Nisimura T, Yamaoka R. Ant nestmate and non-nestmate discrimination by a chemosensory sensillum. Science. 2005 Jul 8;309(5732):311-4.
46. Zhang J, Terrones M, Park CR, Mukherjee R, Monthioux M, Koratkar N, Kim YS, Hurt R, Frackowiak E, Enoki T, Chen Y. Carbon science in 2016: Status, challenges and perspectives. Carbon. 2016 Mar 1;98(70):708-32.