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Nesting habitat and nest structure of the golden mining bee, *Nomia aurata* Bingham (Halictidae: Hymenoptera)

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Abstract
This research examines the nesting biology of the golden mining bee, *Nomia aurata*, at G.B Pant University of Agriculture and Technology Pantnagar (India). It investigates nesting habitat attributes, including vegetation, slope, soil properties, nesting season, activity, nest architecture, and nest contents. Weekly surveys at the Norman E. Borlaug Crop Research Centre and Vegetable Research Centre identified 30 nests in three distinct beds during March-April 2023. Nests were systematically identified and labelled. This study examined the subterranean nesting parameters of 11 *Nomia aurata* bees at varying post nesting intervals. Analysis of the soil samples from 3 nests revealed dry consistency characterized by sand (10-12%), silt (70-75%), and clay (70-75%). Critical parameters such as entrance diameter, tunnel dimensions, brood cell characteristics, and distances within the nest structure were recorded. The entrance, circular in shape, featured a distinctive tumulus-turret, with an average diameter of 2.56±0.13 mm (Mean ± SD). Tunnel length spanned 103 to 166 mm, averaging at 135.16±17.01 mm (Mean ± SD), while the tunnel diameter exhibited an average of 2.91±0.18 mm (Mean ± SD). Brood cell count ranged from 0 to 3, with variable lengths (6.32 to 7.69 mm) and breadths (3.07 to 3.86 mm). Brood cell distances from the entrance displayed variation, with Cell 1 found at a minimum of 53 mm in Nest 1 and a maximum of 151 mm in Nest 4, averaging at 111.11±32.29 mm (Mean ± SD). Similar trends were observed for Cells 2 and 3. Upon microscopic examination, the brood cells revealed distinct shining linings. Notably, the larval stage exhibited creamish coloration, featuring 13 abdominal segments and 10 pairs of spiracles.

Keywords: Golden mining bee, *Nomia aurata*, nests, subterranean

Introduction
Over 20750 species of bees are known to exist and are divided into seven biological groups (Ascher and Pickering, 2023) [2]. More than 97% of bee species are solitary, including mason bees, carpenter bees, leafcutter bees, mining bees and sweat bees. Some species, including honey bees, stingless bees and bumblebees, live in colonies. With 4,510 species, the bee family Halictidae is the second-largest in the clade Anthophila (Ascher and Pickering, 2023) [2]. They are referred to as "Sweat bees" because many species, especially the smaller ones, are drawn to perspiration. They often have metallic undertones, are dark in colour, commonly brown or black, and come in a variety of sizes, colours, and patterns. Some species are coloured green, red, purple, or blue, while the cheeks of the males are frequently yellow. The family is recognised by its sharply curled basal vein on the wing and small tongues. In this family, females often outweigh males in size. Although certain halictid bees may nest in wood, they mainly build their nests on the ground, especially in clay soil and along riverbanks (Antoine and Forrest, 2021) [1]. They provide food in large quantities for their larvae. The mother bee makes a waterproof cell with a concentration of pollen and nectar, lays an egg on top of it, and then closes the cell. As opposed to honey bees, who feed their young gradually, this makes sure the larva gets all of its food at once. Some halictid species cover their tunnels with lactone secretions, which makes it easier for workers to find the nest (Brooks and Cane, 1984) [6]. Highly eusocial bees, like honey bees, are not ground-nesters, but the family Halictidae includes primitively eusocial and socially polymorphic bees that primarily nest in the ground (Waislo and Fewell, 2017) [20]. Nomiinae is a subfamily under the family Halictidae. The Nomiinae subfamily has around 620 species, with the Paleotropics and nearby regions being hotspots of species richness (Michener 2007; Pauly 2009; Ascher and Pickering, 2019) [14, 18, 3]. There are still many unknown morphospecies in this group, especially in Asia. The bees of family Halictidae exhibit variety of biological behaviour ranging from eusociality to solitary (Ayasse and Paxton, 2002; Muller et al., 2006; Danforth et al., 2008; Gibbs et al., 2012; Danforth et al., 2013) [4, 16, 9, 12, 8].

Bees go through a complete metamorphosis, and the length of their life stages varies among species and environmental conditions. Some bee species can produce multiple generations per year, while others take more than a year to complete a generation. Solitary ground nesting bees emerge from their nests, mate, and may be active for only a few weeks (Antoine and Forrest, 2021) [1]. Nomia bees are commonly known as alkali bees. *Nomia aurata* Bingham 1897, commonly known as the golden mining bee, is a species of solitary bee under the tribe Nomiini subfamily Nomiinae of family Halictidae. *Nomia aurata* is an early spring bee species. They typically emerge from their nests and start their nesting activities in the early spring months, around March to April, depending on the region and climate. The timing may vary slightly in different geographic locations (Selfridge *et al.*, 2017) [19]. They are commonly found in a variety of habitats including meadows, grasslands, gardens, and woodland edges. They prefer areas with loose, sandy soil for nesting (Dibble *et al*., 2017) [10]. *Nomia aurata* is a ground-nesting bee, which means that it constructs its nests underground. The Nomia bees excavate the soil using their mandibles and legs, creating a burrow (Dibble *et al*., 2017) [10]. Once the tunnel is complete, the female bee collects pollen and nectar from flowers, bee forms a provision mass by mixing the collected pollen with nectar. The female Nomia bee lays a single egg on top of the provision mass within the tunnel. Nomia bee then seals the chamber with a plug made of soil or plant material, creating a separate cell for each egg (Moissett and Buchanan, 2010) [15]. Nomia bees are capable of producing multiple broods in a single nesting season. Nomia bees often nest in aggregations, meaning multiple females establish their nests close to one another in the same area. This clustering behaviour can be beneficial for the bees, as it provides protection against predators and improves mating opportunities (Esther and Roulston, 2009) [11].

Material and Method

To study the nesting biology of the soil nesting bees *Nomia aurata* observation on the following nesting parameters was recorded during the investigation period. (a) Above ground parameters: Nesting season, Nest density, Direction of the slope, Soil parameters, Vegetation around the nest, Diameter of the nest entrance (b) Below ground parameters: Diameter of nest tunnel, Depth of nest tunnel, Shape of nest tunnel, Number of the cells in nest, Shape of the cells, Size of the cells, Distance of brood cell from the entrance, Cell provision, Faecal pellets, Cell contents, and Cell lining .To study the nesting habitat and nesting shelter, regular surveys at weekly interval were conducted in the potential nesting sites such as Norman E. Borlaug Crop Research Centre and Vegetable Research Centre, roadsides, garden section, hostel premises, where the weed patches was present. For finding the nests, the ground area around the foraging plants in the potential nesting habitats was searched. The Vegetable Research Centre was searched intensively and the nests were located in Vegetable Research Centre. A total of 30 nests of *Nomia aurata* were found during the research period on three different nesting beds. After finding the nest the nest of *Nomia aurata* located in three nesting beds at Vegetable Research Centre during March April 2023 were marked and numbered as Nest 1, Nest 2, Nest 3 and so on. For recording data on belowground nesting parameters, 11 nests were excavated at different intervals after completion of nesting activity of the bees. A round shaped soil clod containing the nest of appropriate size (10 cm radius, considering nest entrance hole as centre) was dug out. The nests were taken to the Entomology laboratory to record further data on cell construction material contents, cell provision and other nest parameters. The extra soil was removed by using the tool such as knife, blade, scrapper etc., to reach the nesting tunnel and to expose the actual nest with cells. Various observations were recorded and the measurements were taken with the help of digital Vernier callipers. The nest cells were carefully opened taking care of their arrangement in the nest and data on cell contents including provision store, brood stage, faecal matter was recorded. The bee specimens were collected from the foraging plants and the nest with the help of sweep net or directly into the killing jar. All the specimen so collected were preserved very carefully in the laboratory for further taxonomic identification. All the collected specimen which was preserved and maintained in the laboratory got identified from Dr. Rifat Hussain Raina Scientist, Zoological Survey of India, Jodhpur (Rajasthan).

Results and Discussion

The *Nomia aurata* bees were found active during the months of February to June. The activity of the bees almost stopped in the last week of the June. 30 nests were located on three nesting beds. The nests were present in aggregation. On the nesting bed 1 the 17 nests were located and the density of the nests was 1.10 nests/m^2. Eight nests were located on the nesting bed 2. The density at the nesting bed 2 was 1.16 nests/$m^{2.}$ At nesting bed 3, five nests were located and the density of the nests was 1.16 nests/m^2. The overall nesting density was 1.12 nests/m^2. The nests were present on the slopy surface ranging from 17-32º, facing east. The soil was having the dry consistency. The relative proportion of sand, silt and clay in all the samples was, sand:10-12%, silt:70-75%, clay:11-15%. The Ph of the soil samples was 7.1. The bulk density of the soil was recorded to be 1.48 g/cm^3. The electrical conductivity of the soil was recorded to be 0.27 ds/m. The patches of grasses were present at the nesting sites and few species of the weeds were present was also present at nesting beds like *Polygonum effusum* and *Lysimachia arvensis*. The diameter of the entrance varied from 2.27 to 2.74 mm with an average of 2.56 ±0.13 mm (mean ±SD). The turrets of soil were also observed around the entrance of the nest.

For recording the below ground parameters 11 nests were excavated. The length of the nest tunnel varied from one nest to another. The bees made their nests 103 to 166 mm deep from the ground level with an average depth of 135.16±17.01 mm. The diameter of nest varied within the nest also at different places. The nest tunnel diameter was taken at three spots (upper, middle and lower parts). The average of all the values within the nest was calculated for calculating the tunnel diameter of a particular nest. The diameter of tunnel varied from 2.66 to 3.23 mm with an average diameter of 2.91±0.19 mm (Mean+SD). The shape of the nest tunnel varied from almost vertically straight downwards (nests 6,7,9 and 10) to having downwards tunnels with curves and slanting vertically (nests 1, 2, 3, 4, 5, 8, 11). The nest tunnel was shaped like a thin pipe. The shape of all the nests tunnels have been depicted with the help of line diagram. The shape

of brood cells was almost similar in all the nests. The brood cells were oval in shape. In some of the nests the brood cells were joined directly to the main tunnel and in few nests they were joined to the main tunnel with the help of short lateral gallery. The size of cells in the different nest of *N. aurata* varied from nest to nest. Their length varied from 6.32 to 7.69 with an average of 6.92±0.45 mm (Mean length of cell 1, 2 and 3, SD of cell 1,2 and 3) (Mean ± SD; n=3) and breadth varied from 3.07 to 3.86 mm with an average breadth of 3.47±0.274 mm (Mean ± SD; n=3). The distance of the 1st, 2nd and 3rd brood cell from the nest entrance varied from one nest to another. Cell 1 was found at the minimum distance of 53 mm in nest 2 from the entrance and it was found at the deepest point of 151 mm from the entrance in nest 4. The average distance of cell 1 from the entrance was 111.11±32.29 mm (Mean+SD; n=9). The cell 2 was found at a minimum distance of 103 mm from the entrance in nest 6 and it was found at the deepest point of 166 mm from the entrance in nest 1. The average distance of cell 2 from the entrance was 126.37±18.32 mm (Mean+SD; n=8). Cell 3 was found only in 3 nests, the minimum distance from the entrance at which the cell 3 found was 124 mm in nest 7 and deepest point at which the cell 3 was located was 139 mm in nest 3. The average distance of cell 3 from the entrance was 131.33±7.50 mm (Mean+SD; n=3). Faecal pallets were collected from the brood cells in which the larvae were present. The faecal pallets were slightly yellowish colour mass. The faecal pallets were barrel shaped and loosely joined in groups of 4-5. The brood cells present in the nest were observed under the microscope. All the brood cells were having some shining lining present in it. The number of brood cells varied from 0-3 in each nest. No brood cells were found in nests 5 and 8, perhaps these were the new and the founding nests. In nests 1,6,9,10 and 11, the number of brood cells were 2. In nests 2,3 and 7, the number of brood cells was 3. In nest 1,2,4,6 and 11, a total of 5 larvae and 1 pupal case was recorded while in nests 3,5,7,8,9 and 10, no immature stages were observed. *Nomia aurata* is a ground-nesting bee which means it constructs nest underground. Nomia bees excavate the soil using their mandibles and legs, creating a burrow (Dibble *et al*, 2017) [10]. Nye (1980) [17] observed that the *Halictus farinosus* plugs the entrance when it leaves or enters the nest. In present study also, *Nomia aurata* was also observed excavating the soil with their posterior abdomen to close the nest. Nye (1980) [17] also observed the presence of tumulus turrets around the nest. The tumulus-turrets were also present around the entrance of nest of *Nomia aurata* in present investigation. *Nomia triangulifera* is a medium sized which are gregarious and often establishes numerous nests in a single site. They nest in soil with wide range of moisture and texture. The ground with well dry with slopes is being preferred (Cross and Bohert, 1960) [7]. *Nomia aurata* bee also preferred the dry soil with gentle slope ranging from 17º to 32º. In present investigation also the numbers of nest of *Nomia auarata* was also present at the nesting beds. Nesting sites for *Nomia tetrazonata* bee had a density of 1 to 14 nests per sq. m (Weislo and Angel, 1996) [21]. *Nomia aurata* bees had the density of 1.12 nest per sq. m. Batra (1966) [5] observed the nest structures of *N. capitata*, *N. oxybeloides*, *N. Punctulate*, and *N. nasicana* all the species construct the nest in soil with vertical burrows. They had the cells arranged in the clusters. *Nomia aurata* also constructed the nest with the vertical burrow but they had the slanting turns in some nests. Few nests had very small lateral tunnels connecting the brood cells. The brood cells of the *Nomia aurata* was not present in clusters rather the nests had only few brood cells ranging from 0-3. McConnell (1994) [13] observed that the bee *Lasioglossum tibiale* used some glandular secretions to waterproof the brood cells. In present investigation also it was observed that the nest of *Nomia aurata* nest had some shining waterproof lining to protect its brood.

Table 1: Nest parameters and nest dimension of *Nomia aurata*

S.no	Entrance diameter (mm) (n= 11)	length of nest tunnel (mm) (n= 11)	Diameter of tunnel (mm) (n= 11)	Total number of brood cells (n=11)	Dimension of brood cells (mm)						Distance of brood cell from entrance (mm)	Distance between brood cells (mm)	Cell lining in brood cells
					1 (n= 8)		2 (n = 7)		3 (n= 3)				
					length	Breadth	Length	Breadth	Length	Breadth			
Nest 1	2.45	166	2.99	2	7.35	3.33	7.19	3.18	--		C1-146 C2-166	11 mm	P
Nest 2	2.61	131	3.23	3	*	*	6.43	3.51	7.47	3.55	C1-1-53 C2-114 C3-131	C2-C3 (17 mm)	P
Nest 3	2.69	139	3.19	3	7.69	3.78	7.36	3.86	7.31	3.81	C1-111 C2-124 C3-139	C1-C2- 2 (6 mm), C2-C3-3 (15 mm)	P
Nest 4	2.55	151	2.98	1	6.57	3.74	---		--		C1—151		P
Nest 5	2.27	138	2.69	0	---		---		--				
Nest 6	2.49	103	2.66	2	6.81	3.18	6.74	3.36	--		C1-74 C2-103	C1-C-2-29	P
Nest 7	2.55	124	2.92	3	6.35	3.55	*		6.46	3.07	C1-97 C2-121 C3-124	C1-C2-24, C2-C3-3 mm	P
Nest 8	2.52	152	2.74	0									
Nest 9	2.57	123	2.84	2	7.24	3.63	7.13	3.47	---		C1-123 C2-123	C1-C2-01 mm	P
Nest 10	2.69	132	2.84	2	6.32	3.39	6.79	3.42	---		C1-132 C2-132	C1-C2-03 mm	P
Nest 11	2.74	128	2.88	2	6.64	3.16	6.78	3.52	---		C1-113 C2-128	14.44 mm	P
Mean	2.56	135.16	2.91		6.87	3.47	6.92	3.47	6.98	3.48	n = (9) C1-111.11 n= (8) C2-126.37 n = (3) C3-131.33		
SEM	0.0186	0.0175	0.0181		0.18	0.073	0.0149	0.0468	0.083	0.046	C1-13.92 C2-6.325 C3-4.245		
SD	0.13	17.01	0.01		0.501	0.241	0.321	0.206	0.542	0.375	C1-32.29 C2-18.32 C3-7.50		

Table 2: Dimension and slope of the nesting beds

S.no	Nesting bed dimension			Total no. of nest	Slope (degree)
	Length (m)	Breadth (m)	Area (m^2)		
Site 1	8.34	2.27	18.93	17	17-18
Site 2	4.17	2.24	9.34	8	24-25
Site 3	2.4	2.24	5.376	6	29-32

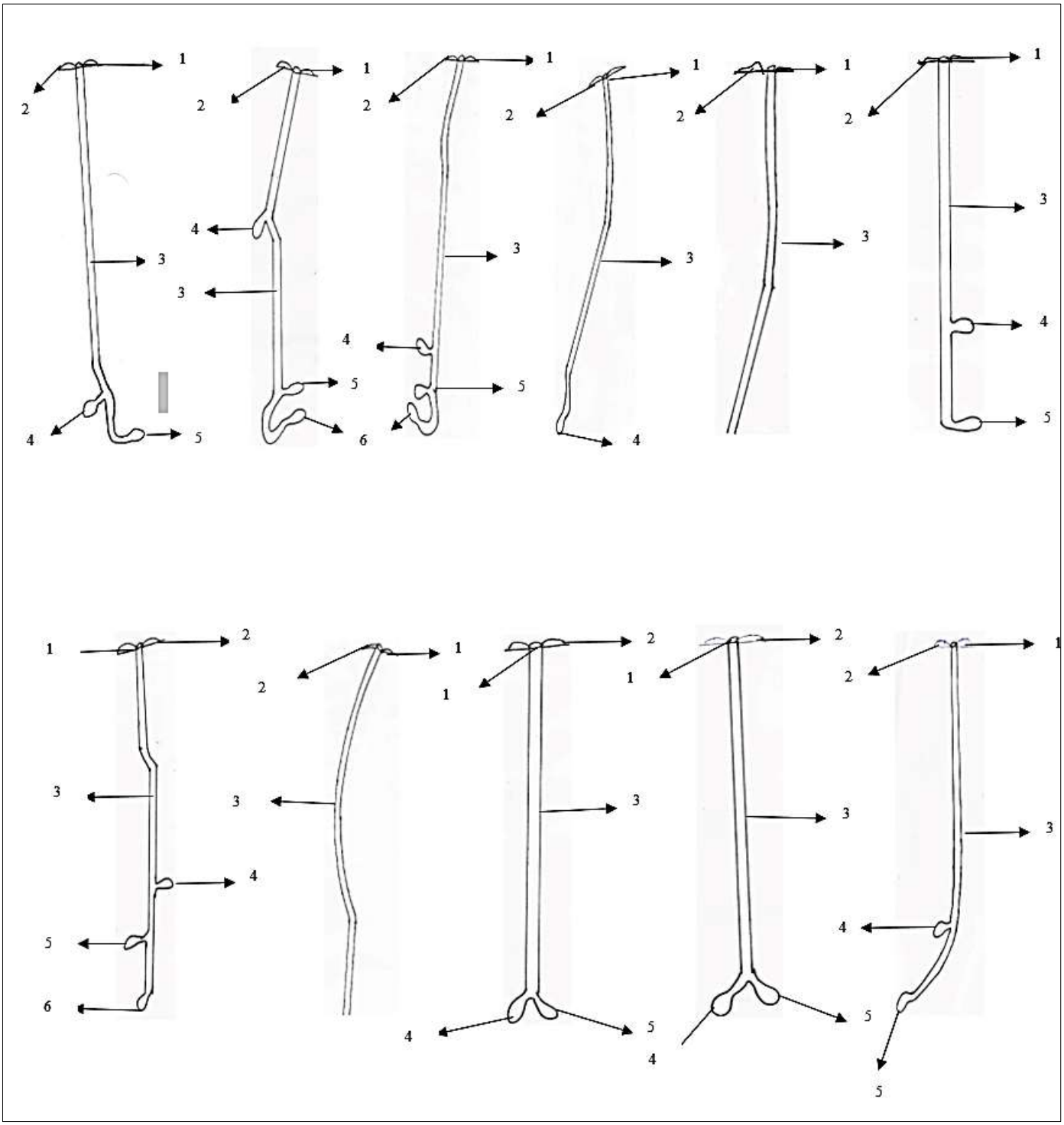

Fig Nest 1 to 6 (left to right) 1st row, Nest 7 to 11 (left to right) 2nd row 1= Nest entrance, 2= Turrets, 3= tunnel diameter, 4= Brood cell 1, 5= brood cell 2, 6= brood cell 3

Fig 1: Line diagrams of 11 nests of *Nomia aurata*

Conclusion

To study the nesting habitat and nesting shelter, regular surveys at weekly interval were conducted in the potential nesting sites such as Norman E. Borlaug Crop Research Centre, Vegetable Research Centre, roadsides, garden section and hostel premises, where the weed patches were present. For finding the nests, the ground area around the foraging plants in the potential nesting habitats was searched. The Vegetable Research Centre was searched intensively and the nests were located in Vegetable Research Centre. A total of 30 nests of *Nomia aurata* were found during the research period on three different nesting beds. After finding the nest the nest of *Nomia aurata* located in three nesting beds at Vegetable Research Centre during March- April 2023 were marked and numbered as Nest 1, Nest 2, Nest 3 and so on. For recording data on belowground nesting parameters, 11 nests were excavated at different intervals after completion of nesting activity of the bees. A round shaped soil clod containing the nest of appropriate size (10 cm radius, considering nest entrance hole as centre) was dug out. The nest bed had the slope in the range of 17-32 degrees. The sample of 3 nests was taken for soil sample randomly. The soil had the dry consistency with same percent of sand (10-12%), silt (70-75%) and clay (70-75%) in each of the sample.

The different parameters like entrance diameter, length of tunnel, diameter of the tunnel, number of brood cells in the nest, length and breadth of brood cells, distance of brood cells from the entrance, distance between the brood cells and the cell lining was observed. The nest entrance was circular in shape with tumulus-turret present around the entrance. The diameter of the entrance varied from 2.27 to 2.74 mm with the average diameter of 2.56±0.13 mm (Mean ± SD). The length of the tunnel varied from 103 to 166 mm with average length of 135.16±17.01 mm (Mean ± SD). The diameter of the tunnel was calculated at the three different place and the average was calculated. The average diameter of the tunnel was 2.91±0.18 mm ((Mean ± SD). The total number of brood cells in the nest varied from 0-3. The length of brood cell varied from 6.32 to 7.69 mm in different cells and the breadth varied from 3.07 to 3.86 mm. The distance of brood cell from the entrance also varied from nest to nest. Cell 1 was found at the minimum distance of 53 mm in nest 1 and it was found at maximum distance of 151 mm in nest 4. The average distance of cell 1 from the entrance was 111.11± 32.29 mm (Mean ± SD). Similarly, the cell 2 was present at the minimum distance of 103 mm from the entrance in nest 6 and was present at the maximum distance of 166 mm from the entrance in nest 1. The cell 2 had the average distance from the entrance of 126.37±18.32 mm ((Mean ± SD). Cell 3 was found at the minimum distance of 124 mm in nest 7 and it was located at deepest point of 139 mm in nest 3. The average distance of cell 3 from the entrance was 131.33±7.50 mm (Mean ± SD). When the brood cells were observed under the microscope the shining lining in the brood cells was clearly observed. The immature stages like larvae and pupal case collected from the brood cells was observed under the microscope in the laboratory. The larva was creamish in colour with 13 abdominal segments and 10 pairs of spiracles.

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