

# Study on the post-embryonic development of *Striatoppia milii* Sanyal & Basu, 2014 (Acari: Oribatida: Oppiidae) on the microfungus *Trichoderma harzianum*

Praveena Karimbakkandi <sup>a</sup>, Sobha Thalakkattil Raghavan <sup>a</sup>

<sup>a</sup> PG and Research Department of Zoology, Farook College (Autonomous), Calicut, Kerala, India.

## Original research

### ABSTRACT

The present work is a study on the post-embryonic development of the oribatid mite *Striatoppia milii* from the family Oppiidae. *Striatoppia milii* specimens were reared under laboratory conditions at a relative humidity of  $80 \pm 2\%$  and temperature of  $27 \pm 2$  °C. During the study time, both adult and immature forms of *S. milii* fed on the microfungus *Trichoderma harzianum*. The total developmental duration of the life stages of *S. milii* from egg to adult was  $21.4 \pm 1.5$  days with five active instars: larva, protonymph, deutonymph, tritonymph and adult. Given their nutritional preferences and short development cycle, they might be used in agriculture by improving the process of biodegradation.

**Keywords** eggs; larva; nymph; ontogeny; life cycle

## Introduction

Oribatid mites, also known as moss mites, armored mites, or beetle mites, are the numerically most abundant members of the class Acari found in soil mesofauna (Krantz and Walter 2009). These chelicerates show a cosmopolitan distribution and can feed on different food items like bacteria, algae, fungi, nematodes, carrions, and leaf litter. Because of the different feeding habits, they play an important role in the decomposition of organic matter, associated nutrient release, and detritus food chain maintenance in soil (Walter and Proctor 1999). Studies on the developmental biology of oribatid mites are an important aspect of Acarology because these studies can help to develop strategies to use their ability in biodegradation of leaf litter and nutrient release. The ontogeny and duration of the development of oribatid mites have often been investigated, but the literature is not always suitable for comparison and interpretation (Ermilov and Łochyńska 2008). These complications are mainly because of the use of various cultivation techniques, lack of recorded lengths of development for separate stages, and unavoidable fluctuations of air temperature (Shaldybina 1969a; Seniczak 1972; Hartenstein 1962; Block 1965; Weigmann 1975).

The duration of the developmental period of oribatid mites is different under different environmental conditions, such as temperature, soil acidity, humidity, and amount and quality of food (Shaldybina 1969b; Siepel 1994; Maraun and Scheu 2000; Uvarov 2003). According to Siepel (1994), the genetic mode has a stronger influence on the developmental time than other factors, which is why the variation in developmental time induced by the environment is smaller than variations in the developmental time of microarthropods within families or orders.

The current study is focusing on the post-embryonic development of the oribatid mite *Striatoppia milii* Sanyal & Basu, 2014, from the family Oppiidae. Oppiidae is one of the largest

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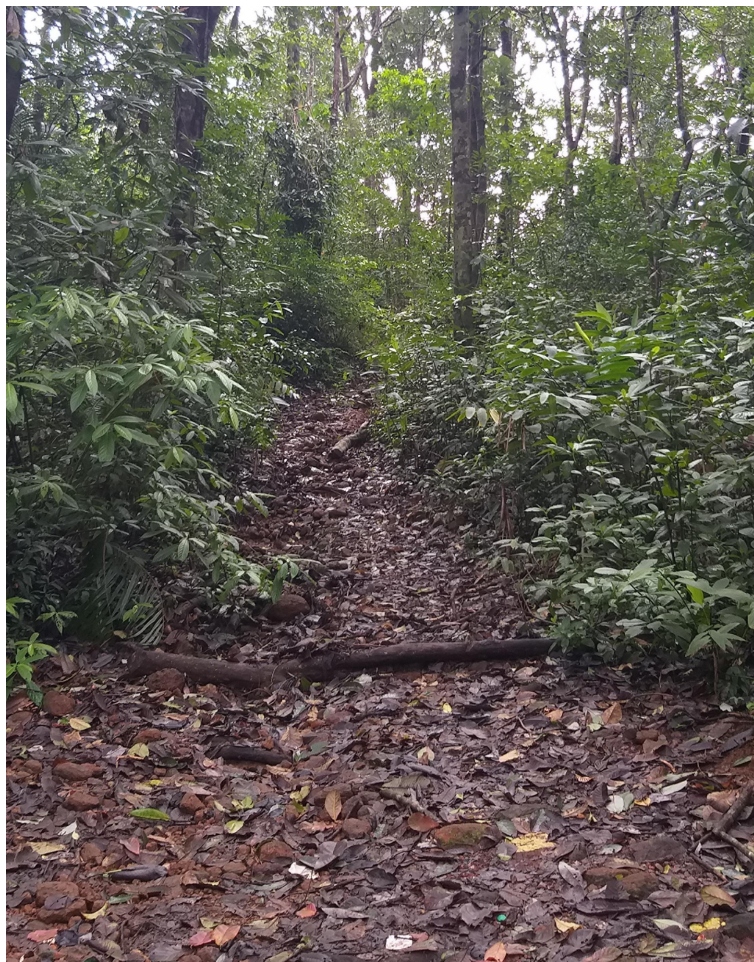


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Raghavan S.

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**Figure 1** Sample collection site Kakkadampoyil (Kerala).

families in the suborder Oribatida, comprising about 132 genera, 41 subgenera, and 1048 species; they are distributed worldwide (Subías 2014 update 2021). The members included in the family Oppidae are mainly fungivores (Seniczak 1975). In India, the family Oppidae comprises about 26 genera and, among these, the genus *Striatoppia* comprises eight species. The key feature of the members of *Striatoppia* is the name-giving striations of their notogaster (Sanyal, 2009). *Striatoppia milii* was first reported in India by Sanyal and Basu (2014) from Agatti Island, Lakshadweep.

## Material and methods

### Study area

Soil and litter samples were collected from Kakkadampoyil (geographic coordinates: 11.3318°N, 76.1102°E, elevation 650m above sea level), in the Calicut district of Kerala, India. The sampling site is a part of moist deciduous forest in the southern part of the Western Ghats, comprising a wide variety of flora and fauna. The most common trees are *Albizia lebbeck*, *A. procera*, *Alstoniascholaris* sp., *Ficus callosa*, *Bauhinia malabarica*, *Cassia fistula* (N. Sasidharan 2006) (Fig. 1).

## Collection of mites

Sampling was done during the pre-monsoon season, from January to June 2019, in the early morning at about 8 am. Samples were collected randomly using a metal corer (5x5x10 cm) from about 10-15 cm depth. From the collection site, semi-degraded leaves, twigs, and fungi were also collected along with the soil and put into plastic bags. The plastic bags were labeled after sample collection and taken into the laboratory for extraction as soon as possible.

## Extraction and identification of mites

The extraction of mites was done using a Berlese-Tullgren Funnel apparatus. The mites were extracted into culture vessels containing powdered and moistened leaf litter (the plant materials in various stages of decay were collected from the sampling site, were dried at 60 °C and grounded to a powder). The process of extraction was completed within 3–4 days.

For taxonomic studies, the oribatid mites were directly collected into 70% alcohol, then dehydrated using 80%, 90%, and absolute alcohol and kept in a clearing medium, which comprises ethyl alcohol and lactic acid (1:1 ratio) for 3 weeks. After sufficient clearing, the specimens were carefully mounted in polyvinyl alcohol (PVA) on micro slides, and glass bristles (1 mm thick) were used to prevent damage to the specimen. The morphological characters of mounted specimens were examined through a Compound Microscope (Magnus). The identification was done using taxonomic keys, (Balogh and Mahunka 1983; Balogh and Balogh 1990; Balogh and Balogh 1992; and Subías 2014 edition updated in 2021) and it was confirmed with the help of Dr. Ramani N., Professor, Division of Acarology, University of Calicut.

## Preparation of culture vessels and rearing of mites

Adults of *S.milii* were separated from the extracted living mites using a moistened camel hairbrush under a Stereo Zoom Microscope (Labomed). Ten adult *S. milii* were introduced into each culture vessel, which was based on plaster of paris and activated charcoal at a ratio of 4:1 for subsequent rearing (Haq and Ramani 2002). The culturing of the mite species was done by providing different food items like algae (*Protococcus*), fungi (*T. harzianum*) (Fig. 2a), carrions of small soil arthropods (Fig. 2b), and different leaf litters. Further rearing of the mite species was carried out on *T. harzianum* to study its post-embryonic development, as the mites fed voraciously on this food item in the culture vessels. The culture vessels were kept in the desiccators to maintain a constant relative humidity of 80±2% and temperature 27±2 °C during the entire period of investigation.

## Study of the life stages of *Striatoppia milii*

The culture vessels were examined after every 12 hours to study the reproductive biology of the mite *Striatoppia milii*. The culture base and the food material provided were scanned for spermatophores or eggs, and ovipositional behavior of females was studied. When eggs were detected, they were transferred into separate culture vessels using a fine camel hair brush with maximum care. A minimum of 10 eggs was introduced into each culture vessel and further development of the eggs was followed closely. All available information about the egg's incubation, hatching, larval and nymphal stages, intervening quiescent and moulting phases, etc. was recorded. Photographs of the various life stages were taken using the camera-attached Stereo Zoom Microscope (Labomed). Permanent slides of different life stages of *S.milii* were prepared using live juveniles from a separate culture vessel. Non-sclerotized juvenile forms were directly mounted in polyvinyl alcohol (PVA) on micro slides. The adult *S.milii* were treated like described above. The morphological characters of mounted specimens were examined through a Compound Microscope. The measurements were taken using an ocular micrometer. Details regarding the duration of development of the F1 generation and the duration of individual life stages were recorded and tabulated (Table 1).





**Figure 2** a – Adults and nymphs feeding on microfungus *Trichoderma harzianum* (*T. harzianum* indicated by arrow). b – Adult *S. milii* feeding on a dead immature centipede.

## Results

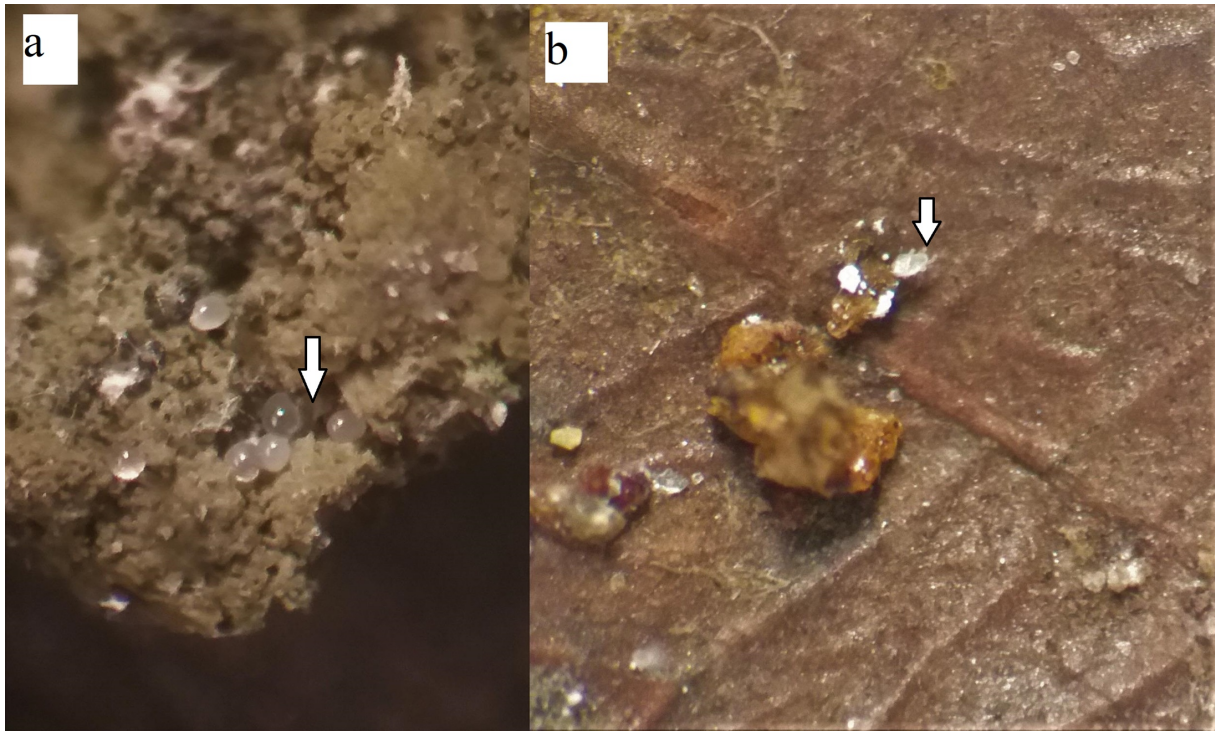
### Oviposition

Adult females ( $n=10$ ) of *Striatoppia milii*, deposited eggs in the holes present in the substratum, sides of the culture vessel, and inside the provided food item (*Trichoderma harzianum*). A single female *S. milii* could oviposit about 10–15 eggs within the oviposition period which lasted about  $10 \pm 2$  days. They deposited eggs in the holes present in the substratum, sides of the culture vessel, and inside the provided food item as a cluster of 6–10 eggs or solitary egg (Fig. 3a). The eggs of *S. milii* were oval-shaped with  $64.4 \pm 3$   $\mu\text{m}$  in width and  $84.4 \pm 3$   $\mu\text{m}$  in length (Table 2). The total incubation period from egg to larva was  $6.5 \pm 0.5$  days and just before the hatching, the colour of the eggs changed from transparent to creamy white. During the time of hatching, a slit was formed in the anterior end of the egg and mouthparts and the first pair of appendages came out through this opening. The larvae completely emerged through this opening within 6–7 hours (Fig 3b).

### Duration of life stages

#### Larva

The newly emerged hexapod larvae were very small, with  $67.2 \pm 3$   $\mu\text{m}$  width and  $87.6 \pm 3$   $\mu\text{m}$  length (Table 2). The body was rectangular-shaped with a wrinkled, soft, and transparent cuticle. Just after the emergence, they were inactive and did not feed, but within 3–4 hours, they became active, started feeding, and their wrinkled cuticle became smooth and the body formed an oval shape. The larvae were good feeders on microfungi *Trichoderma harzianum* and we could see green fungal food boluses inside the body through their transparent cuticle. These larvae actively fed for  $2.1 \pm 0.3$  days, and the body became swollen with a creamy white



**Figure 3** a – A cluster of eggs on *Trichoderma harzianum*. b – Hatching of larvae from an egg (indicated by arrow).

colour and subsequently entered the first quiescent stage. The first quiescent period was about  $1.2\pm1$  days and after this, they started moulting. A vertical slit formed at the posterior region of the larva and through this slit, the protonymph came out with a wriggling movement. The moulting process was completed within 6–7 hours.

**Table 1** Duration of post-embryonic stages of *Striatoppia milii* in days, under laboratory conditions (Relative humidity =  $80\pm2\%$  and temperature =  $27\pm2$  °C). Abbreviations: E = Egg, Ind = Individual, Lv = Larva, Pn = Protonymph Dn=Deutonymph, Tn= Tritonymph, Q1-Q4= Quiescence stages.

| Ind  | E           | Lv          | Q1        | Pn        | Q2          | Dn        | Q3        | Tn        | Q4        | Total        |
|------|-------------|-------------|-----------|-----------|-------------|-----------|-----------|-----------|-----------|--------------|
| 1    | 7           | 2           | 1         | 2         | 1           | 2         | 1         | 3         | 2         | 21           |
| 2    | 7           | 2           | 1         | 2         | 1           | 2         | 1         | 3         | 1         | 20           |
| 3    | 6           | 2           | 1         | 2         | 2           | 2         | 1         | 4         | 1         | 21           |
| 4    | 7           | 2           | 2         | 3         | 1           | 2         | 2         | 3         | 1         | 23           |
| 5    | 7           | 2           | 1         | 2         | 1           | 3         | 1         | 4         | 2         | 23           |
| 6    | 7           | 3           | 1         | 2         | 2           | 3         | 1         | 3         | 1         | 23           |
| 7    | 6           | 2           | 2         | 3         | 1           | 2         | 2         | 3         | 1         | 22           |
| 8    | 6           | 2           | 1         | 2         | 2           | 2         | 1         | 3         | 2         | 21           |
| 9    | 6           | 2           | 1         | 2         | 1           | 2         | 1         | 3         | 1         | 20           |
| 10   | 6           | 2           | 1         | 2         | 2           | 2         | 1         | 3         | 1         | 20           |
| Mean | $6.5\pm0.5$ | $2.1\pm0.3$ | $1.2\pm1$ | $2.2\pm1$ | $1.4\pm1.5$ | $2.2\pm1$ | $1.2\pm1$ | $3.2\pm1$ | $1.3\pm1$ | $21.4\pm1.5$ |

**Table 2** Average body width and length of different developmental stages of *Striatoppiamillii* (in  $\mu\text{m}$ ); n=10.

| Stage      | Width         | Length        |
|------------|---------------|---------------|
| Egg        | 64.4 $\pm$ 3  | 84.4 $\pm$ 3  |
| Larvae     | 67.2 $\pm$ 3  | 87.6 $\pm$ 3  |
| Protonymph | 82 $\pm$ 3    | 102.4 $\pm$ 3 |
| Deutonymph | 100.2 $\pm$ 3 | 122 $\pm$ 3   |
| Tritonymph | 107.6 $\pm$ 3 | 154.4 $\pm$ 3 |
| Adult      | 112.6 $\pm$ 3 | 206 $\pm$ 2   |

### Protonymph

The protonymphs had a transparent, oval-shaped body with four pairs of legs. They were larger than the larvae with 82 $\pm$ 3  $\mu\text{m}$  width and 102.4 $\pm$ 3  $\mu\text{m}$  length (Table 2). They voraciously fed for 2.2 $\pm$ 1 days and then entered the second quiescent stage. During this time, they suspended all life activities and became inactive, and formed a creamy white coloured cuticle. The quiescent period lasted for 1.4 $\pm$ 1.5 days, followed by moulting and emerging of the deutonymph. Similar to larvae, the protonymphs also completed moulting within 6–7 hours.

### Deutonymph

The Deutonymph had an elongated body with a transparent cuticle. They were larger than protonymph with 100.2 $\pm$ 3  $\mu\text{m}$  width and 122 $\pm$ 3  $\mu\text{m}$  length (Table 2). They were active feeders for up to 2.2 $\pm$ 1.2 days and then entered the third quiescent stage. The quiescent period lasted about 1.2 $\pm$ 1. After this, they started moulting. Within 6–8 hours, they completed moulting and emerged as a tritonymph.

### Tritonymph

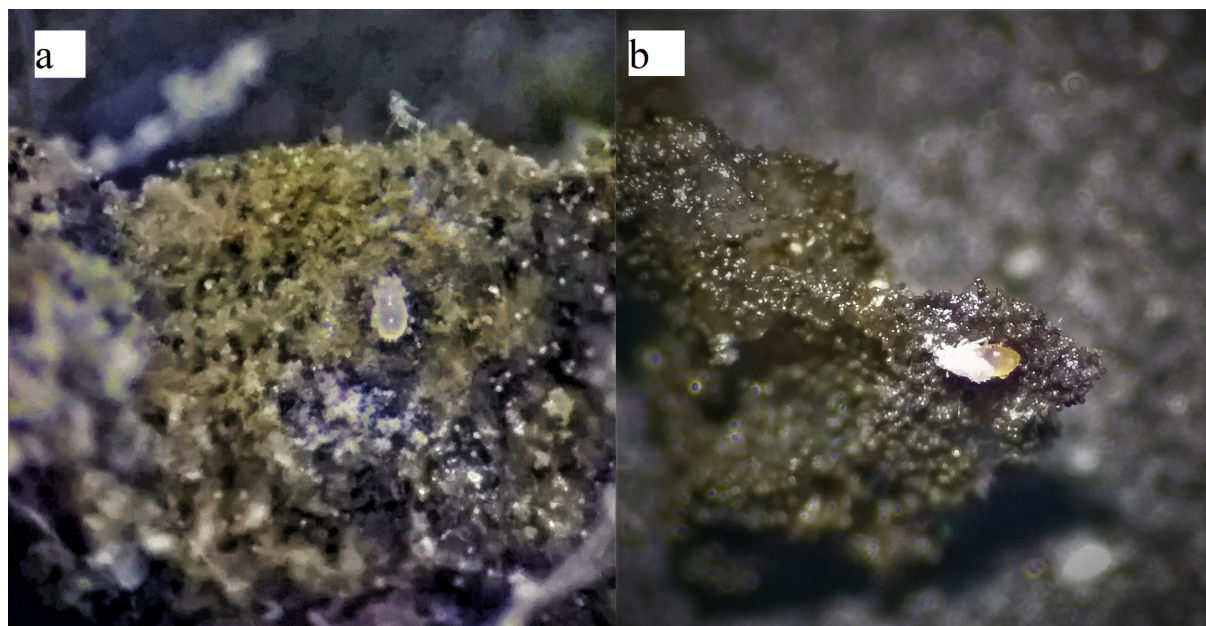
Newly emerged tritonymphs could be easily distinguished from other instars of *S. milii*. The tritonymphs were larger than deutonymphs with 107.6 $\pm$ 3  $\mu\text{m}$  width and 154.4 $\pm$ 3  $\mu\text{m}$  length (Table 2). They were voracious feeders for about 3.2 $\pm$ 1.2 days and then entered the third quiescent stage (Fig 4a). The quiescent period lasted for 1.3 $\pm$ 1.4 days, after that they started moulting (Fig 4b). During the final moulting, a horizontal slit was formed at the posterior part of the tritonymph. The notogaster of the adult mite emerged through this slit. The total time duration for completing this moulting was 12–24 hours, which was longer than the moulting durations of the juvenile stages.

### Adult

Newly formed adults of *S. milii* have a semi-transparent light golden coloured, weakly sclerotized exoskeleton with 112.6 $\pm$ 3 width and 206 $\pm$ 2 length (Table 2). After 2–3 days, the cuticle became hard, well sclerotized, with a dark brown colour with visible barbed setae.

The total duration for post-embryonic development in *S. milii* was very short and completed within 21.4 $\pm$ 1.5 days. The newly moulted adult *S. milii* attained sexual maturity within 11 $\pm$ 2 days and then females started oviposition. The species does not show any dimorphism except that the gravid females are slightly larger than others, so the gender of living specimens could not be determined. Analysis of microscopic slides of adult *S. milii* revealed only females, and no spermatophores produced by males were observed during the present study.





**Figure 4** a – Tritonymph just before moulting. b – Adult emerging from tritonymphal exuvia in the laboratory.

## Discussion

In oribatid mites, the mode of reproduction differs between groups. Parthenogenesis is very common in oribatids compared to other microarthropods. About 10% of oribatid mites can reproduce parthenogenetically, which supposedly aids them in long-term survival and against radiation (Norton and Palmer 1991; Heethoff *et al.* 2009). Sexual reproduction on the other hand helps them to form genetically diverse generations and enhanced chances for adaptations to adverse environmental conditions and limited resource accessibility (Fischer *et al.* 2014). In the present study, we found neither males of *S. milii* nor spermatophores produced by males. As the original description of *S. milii* is also based only on females (Sanyal and Basu 2014), our findings suggest that this species might be parthenogenetic.

## Oviposition

The model Oribatid mite species *Archegozetes longisetosus* is a parthenogenetic mite that laid eggs on the 8<sup>th</sup> day after emergence and completed its oviposition on the 32<sup>nd</sup> day. The clutch size of eggs ranged between 2 and 30 within 24 days of the oviposition period (Heethoff *et al.*, 2007). Another member of Oribatid mites from the family Nanhermannidae, *Nanhermannia coronata* exhibited thelytokous parthenogenesis and in them, the females can lay eggs during all their life till the moment of death (Ermilov 2009). In the present study, *S. milii* is found to start oviposition within 11±2 days after emergence with a maximum number of 10–15 eggs within the ovipositional period, which lasted 10 days. Oribatid mites like *Oppia sticta* and *Multioppia wilsoni* deposited eggs within 3–4 days after the final moult (Shereef 1976), and *Ramusella philippinensis* started oviposition after 7–8 days (Julie and Ramani, 2013).

The pattern of oviposition is different in oribatid mites. They oviposit eggs either solitary, aggregated, or both. According to the studies of Sengbusch (1954), in Galumnoid mites like *Galumna longipluma*, *Galumna elimatus*, and *Galumna nervosus*, the adult females deposit 4–8 eggs in an aggregated form. Their eggs have a thin viscous coating on the surface, which helps the eggs to clump each other and adheres to other substrates. In *Orthogalumna terebrantis* (Cordo and DeLoach, 1975), *Paralamellobates bengalensis* (Haq and Ramani, 1984), *Pelokylla*

*malabarica*, and *Pelokylla omniphagus* (Clement and Haq, 1984), the adult females only deposit solitary eggs. In the case of *Atropacarus chaliyamensis*, they mostly deposit solitary eggs which are rarely found in a cluster (Haq 2019). In the present study, the adult females of *S. milii* could deposit either solitary eggs or clusters of 6–10 eggs under laboratory conditions. A similar observation has been reported in *Li acarus cidarus*, in which females at one oviposition deposited from 3 to 12 eggs either singly or in groups. At the same time, the deposited eggs or eggs removed from dissected females were covered with a sticky material that may inhibit the attack of mold (Arlian and Wooley 1970), but the eggs of *S. milii* did not possess such a viscous coating on their surface. It is interesting to note that the adults of *S. milii* performed oviposition inside the holes, food particles, exuviae, or excreta present in the culture vessel by using it as a form of camouflage to protect the eggs from predators. Concordant observation was noticed in the members of *Pergalumna ekaterinae* (Páez *et al.*, 2019).

## Eggs

Morphological variation of eggs has been reported in different species of oribatid mites, such as ellipsoid appearance in *A. longisetosus*, rounded in *Hydrozetes lemnae*, and oval to elliptical or frequently kidney-shaped in *Mahunkaia tricornis* (Heethoff, *et al.* 2007; Ermilov 2006; Schatz 2002). The eggs of *S. milii* were oval-shaped, which was found similar to *Haplacarus davisii*, *Carabodes subarcticus*, and *Nanhermannia coronata* (Alphonsa and Haq 2006; Ermilov 2011; Ermilov 2009). In some oribatid mites like *Li acarus cidarus*, and *Carabodes subarcticus*, their transparent eggs become pigmented towards the time of hatching (Arlian, and Woolley 1970; Ermilov 2011). In *Atropacarus chaliyamensis* during the time of egg hatching, a tiny black patch appeared within the eggshell and this patch darkened and became more prominent, leading to the formation of a split along with the eggshell (Haq 2019). Contrary to the above observations, the transparent eggs of *S. milii* did not develop any pigmentation or patches; instead they form a creamy white colour just before hatching.

## Juvenile stages

The larval and nymphal instars of *S. milii* were characterized by a semitransparent integument without sclerotization during their entire post-embryonic developmental period. It is in conformity with the findings of Kaneko (1988), that the juveniles of *Oppiella nova* were poor in development of body cuticle and therefore probably more vulnerable to predation. Heethoff (2012) also commented that the weakly sclerotized juvenile forms of oribatid mites may be vulnerable to predation and he also stated that most oribatid mites have exocrine oil glands in all developmental stages, possibly rendering chemical defense the crucial survival strategy in juvenile oribatids. Contrary to this, in the oribatid mite *Acrotrititia clavata*, the cuticle of the larva was weakly sclerotized and the rutella of subcapitulum and its digits showed very little sclerotization with light brown colour (Syamjith and Ramani 2013). Similarly, in the juvenile stages of *Pilogalumna crassiclava*, *Gustavia microcephala*, *Pedrocortesella africana*, *Aleurodamaeus africanus*, *Epidamaeus kamaensis*, *Porobelba spinosa*, the cuticle was weakly sclerotized and the colour of gnathosoma, cornicle, apophyses of gastronotal setae and legs amplifies following the further developmental stages, that is from protonymph to adult (Seniczak and Seniczak 2007; Ermilov 2010; Ermilov *et al.* 2010, Ermilov and Łochyńska 2009).

In oribatid mites, there is a quiescent period between all active developmental stages (Krantz and Walter 2009). During this period, the mites become inactive and stop all physical activities, including feeding. The duration of the quiescent period varies between different oribatid mite species. In the case of *Oppia nitens*, the quiescent period lasted for 2–3 days (Sengbusch and Sengbusch, 1970). In *Atropacarus chaliyamensis* the quiescent period is about 3–4 days and in *Heptacarus hirsutus* it lasted for 9–12 days (Haq 2019). During the present study, the quiescent period of *S. milii*, was only  $1 \pm 0.4$  days.



The members of oribatid mites from temperate or boreal regions take a few days to complete their post-embryonic development, while the species from polar and mountainous temperate regions take 5–8 years (Pfingstl and Schatz 2021). The oribatid mites *Alaskozetes antarcticus* and *Ameronothrus lineatus* take 5 to 8 years for complete post-embryonic development when they are reared in polar climatic conditions (Block and Convey 1995; Søvik and Leinaas 2003). Contrary to this, the developmental duration was only 12 days in *Oppia neerlandica*, 11–16 days in *Niloppia sticta*, 16–23 days in *Multioppia wilsoni*, and 34 days in *Granuloppia* sp. at a temperature of 25 °C at laboratory conditions (Woodring and Cook 1962; Shereef 1976; Shereef 1972). Similarly, *S. milii* have a short post-embryonic developmental period that is  $21.4 \pm 1.5$  days at  $80 \pm 2\%$  relative humidity and  $27 \pm 2$  °C temperature in the laboratory.

## Possible implications for agriculture/biodegradation

Fungi are important primary decomposers in terrestrial ecosystems. They can break down organic matter in to simpler forms and thus increase nutrient availability in the soil. Oribatid mites have an close relationship with soil fungi. Studies already reported that fungivorous oribatid mites have the potential to affect the fungal spore dispersion, succession and the interaction between competing fungal species (Mitchell and Parkinson 1976; Behan and Hill 1978; Visser 1985; Tiunov and Scheu 2005). Therefore, oribatid mites have an indirect effect on decomposition through the modification of soil fungal community structure. In the present study, all stages of *S. milii* are voracious feeders of fungi and they can be easily cultured and reared in the laboratory condition. They have a very short post embryonic developmental period and 99% of the newly hatched mites attain sexual maturity without fail. These unique features of *S. milii* may allow for their application in agriculture as they improve the process of biodegradation and nutrient cycling in the soil ecosystem.

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## Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

## ORCID

Praveena Karimbakkandi  <https://orcid.org/0000-0003-4864-0907>

Sobha Thalakkattil Raghavan  <https://orcid.org/0000-0001-6311-6455>

## References

- Alphonsa X., Haq M. A. 2006. Reproductive biology and life history stages of *Haplacarus davisi* (Acari, Oribatei). *Zoos print j.*, 21: 2272-2276. <https://doi.org/10.11609/JoTT.ZPJ.1417.2272-6>
- Arlian L. G., Woolley T. A. 1970. Observations on the biology of *Liacarus cidarus* (Acari: Cryptostigmata, Liacaridae). *J. Kans. Entomol. Soc.*: 297-301.
- Balogh J., Balogh P. 1990. Oribatid mites of the Neotropical region II. Elsevier Science Publishers. pp. 330.

- Balogh J., Balogh P. 1992. The oribatid mites genera of the world (Vol. 1). Hungarian Natural History Museum. pp. 260.
- Balogh J., Mahunka S. 1983. The soil mites of the world. Volume I. Primitive oribatids of the Palaearctic Region. Elsevier: 360-372.
- Behan V. M., Hill S. B. 1978. Feeding habits and spore dispersal of oribatid mites in the North American arctic. *Rev. Ecol. Biol. Sol.*, 15(4): 497-516.
- Block W. 1965. The life histories of *Platynothrus peltifer* (C.L. Koch, 1839) and *Damaeus clavipes* (Hermann, 1804) (Acarina: Cryptostigmata) in soils of Pennine Moorland. *Acarologia* 7: 735-743.
- Block W., Convey P. 1995. The biology, life-cycle and ecophysiology of the Antarctic mite *Alaskozetes antarcticus*. *J. Zool. London*. 236 (3): 431-449. <https://doi.org/10.1111/j.1469-7998.1995.tb02723.x>
- Clement A., Haq M. A. 1984. Biology of *Pelokylla malabarica* (Acari: Oribatei). In: *Acarology VI*. Griffiths, D.A. and Bowman, C.E. (Eds). Ellis Howood Ltd, Chichester, England. P. 847-854.
- Cordo H. A., DeLoach C. J. 1975. Ovipositional specificity and feeding habits of the water hyacinth mite, *Orthogalumna terebrantis*, in Argentina. *Env. Entomol.* 4(4): 561-565. <https://doi.org/10.1093/ee/4.4.561>
- Emilov S. G. 2006. The life cycle of *Hydrozetes lemnae* (Oribatei, Hydrozetidae). *Entomol. Rev.* 86(2): 177-181. <https://doi.org/10.1134/S0013873806110108>
- Emilov S. G. 2009. The ontology of oribatid mite *Nanhermannia coronata* (Acari, Oribatida, Nanhermanniidae). *Entomol. Rev.* 89: 429-437. <https://doi.org/10.1134/S0013873809030099>
- Emilov S. G. 2010. Morphology of juvenile stages of *Gustavia microcephala* (Acari, Oribatida, Gustaviidae). *Acarina* 18(1): 73-78. <https://doi.org/10.1134/S0013873810010082>
- Emilov S. G. 2011. The biology of the development of the Oribatid Mite *Carabodes subarcticus* (Acari, Carabodidae). *Entomol. Rev.* 91(4): 515-523. <https://doi.org/10.1134/S0013873811040154>
- Emilov S. G., Łochyńska M. 2008. The influence of temperature on the developmental time of three oribatid mite species (Acari, Oribatida). *North West J. Zool.* 4(2): 274-281.
- Emilov S. G., Łochyńska M. 2009. Morphology of juvenile stages of *Epidamaeus kamaensis* (Sellnick, 1925) and *Porobelba spinosa* (Sellnick, 1920) (Acari: Oribatida: Damaeidae). *Ann. Zool.* 59 (4): 527-544. <https://doi.org/10.3161/000345409X484919>
- Emilov S. G., Sidorchuk E. A., Rybalov L. B. 2010. Morphology of juvenile stages of *Pedrocortesella africana* Pletzen, 1963 and *Aleurodamaeus africanus* Mahunka, 1984 (Acari: Oribatida). *Ann. Zool.* 60(3): 391-406. <https://doi.org/10.3161/000345410X535389>
- Fischer B. M., Meyer E., Maraun M. 2014. Positive correlation of trophic level and proportion of sexual taxa of oribatid mites (Acari: Oribatida) in alpine soil systems. *Exp. Appl. Acarol.* 63(4): 465-479. <https://doi.org/10.1007/s10493-014-9801-3>
- Haq M. A. 2019. Potential of oribatid mites in biodegradation and mineralization for enhancing plant productivity. *Acarol. Stud.* 1(2): 101-122.
- Haq M. A., Ramani, N. 1984. Post-embryonic development of *Paralamellobates bengalensis* Bhaduri & Chaudhuri 1968 (Acari: Oribatei) parasitic on *Dioscorea alata*. In: Griffiths, D.A. and Bowman, C.E. (Eds). *Acarology VI*. Ellis Horwood England. p. 819-825.
- Haq M. A., Ramani, N. 2002. Sampling, extraction, and identification of oribatid mites. In: Yadav, P.R., Chauhan, R. Putatunda, B.N. and Chhiliar, B.S. (Eds). ICAR Centre of Advanced Studies, Department of Entomology CCSS, Haryana Agricultural University, Hisar, India. p. 195-212.
- Hartenstein R. 1962. Soil Oribatei. V. Investigation on *Platynothrus peltifer* (Acarina; Camisiidae). *Ann. Entomol. Soc. Am.*, 5: 709-713. <https://doi.org/10.1093/aesa/55.6.709>
- Heethoff M., Laumann M., Bergmann P. 2007. Adding to the reproductive biology of the parthenogenetic oribatid mite, *Archeogozetes longisetosus* (Acari, Oribatida, Thrypochthoniidae). *Turk Zool Derg.* 31: 151-159.
- Heethoff M., Norton R. A., Scheu S., Maraun M. 2009. Parthenogenesis in oribatid mites (Acari, Oribatida): evolution without sex. In *Lost Sex*. Springer, p. 241-257. [https://doi.org/10.1007/978-90-481-2770-2\\_12](https://doi.org/10.1007/978-90-481-2770-2_12)
- Heethoff M., Rasputnig G. 2012. Expanding the 'enemy-free space' for oribatid mites: evidence for chemical defense of juvenile *Archeogozetes longisetosus* against the rove beetle *Stenus junco*. *Exp. Appl. Acarol.*, 56(2): 93-97. <https://doi.org/10.1007/s10493-011-9501-1>
- Julie E., Ramani N. 2013. Studies on the post-embryonic development of *Ramusella philippinensis* on decayed pneumatophores at 70% RH and 30±1°C. In *23rd Swadeshi Science Congress*. p. 663-670.
- Kaneko N. 1988. Life history of *Oppiella nova* (Oudemans) (Oribatei) in cool temperate forest soils in Japan. *Acarologia*, 29(2): 215-221.
- Krantz G. W., Walter D. 2009. A Manual of Acarology. Texas Tech University Press. 3. pp. 704.
- Maraun M., Scheu S. 2000. The structure of the oribatid mite communities (Acari, Oribatida); patterns, mechanisms, and implications for future research. *Ecography*, 23: 374-383. <https://doi.org/10.1111/j.1600-0587.2000.tb00294.x>
- Mitchell M. J., Parkinson D. 1976. Fungal feeding or Oribatid mites (Acari: Cryptostigmata) in an aspen woodland soil. *Ecology*, 57(2): 302-312. <https://doi.org/10.2307/1934818>
- Sasidharan N. 2006. Illustrated manual on tree flora of Kerala supplemented with computer-aided identification. Kerala forest research institute Peechi: 690-698.
- Norton R. A., Palmer S. C. 1991. The distribution, mechanisms, and evolutionary significance of parthenogenesis in oribatid mites. *The Acari*: 107-136. [https://doi.org/10.1007/978-94-011-3102-5\\_7](https://doi.org/10.1007/978-94-011-3102-5_7)
- Norton R. A., Kethley J. B., Johnston D. E., O'Connor B. M. 1993. Phylogenetic perspectives on genetic systems and reproductive mode of mites. In: Wrensch D. L., Ebbert M. A (Eds). *Evolution and diversity of sex ratio in insects and mites*. Chapman & Hall. p. 8-99. [https://doi.org/10.1007/978-1-4684-1402-8\\_2](https://doi.org/10.1007/978-1-4684-1402-8_2)

- Páez J. A. I. R., Villagomez F., Palacios-Vargas J. G. 2019. Description of a new *Pergalumna* (Acari: Oribatida: Galumnidae) species from Mexico and its post-embryonic development. *Zootaxa*, 4647(1): 401-422. <https://doi.org/10.11646/zootaxa.4647.1.25>
- Pfingstl T., Schatz H. 2021. A survey of life spans in Oribatida excluding (Acari) Astigmata. *Zoosymposia*, 20: 7-27. <https://doi.org/10.11646/zoosymposia.20.1.4>
- Sanyal A. K. 2009. A new subgenus and two new species of the family Oppiidae (Acarina: Oribatida) from India. *Rec. zool. Surv. India*, 109(3): 5-9. <https://doi.org/10.26515/rzsi/v109/i3/2009/158987>
- Sanyal A. K., Basu P. 2014. Oribatid mites (Acari: Oribatida) of Lakshadweep. *Rec. Zool. Surv. India*, 114(3): 399-402.
- Schatz H. 2002. *Mahunkaia* n. gen. (Acari Oribatida Eremaozetidae) from Africa. *Trop. Zool.*, 15(1): 105-120. <https://doi.org/10.1080/03946975.2002.10531169>
- Sengbusch H. G. 1954. Studies on the life history of three oribatoid mites with observations on other species (Acarina, Oribatei). *Ann. Entomol. Soc. Am.*, 47(4): 646-667. <https://doi.org/10.1093/aesa/47.4.646>
- Sengbusch H. G., Sengbusch C. H. 1970. Post-embryonic development of *Oppia nitens* (Acarina: Oribatei). *J.N.Y. Entomol.*: 207-214.
- Seniczak A., Seniczak S. 2007. Morphology of juvenile stages of *Pilogalumna crassiclava* (Berlese, 1914) and *P. ornatula* Grandjean, 1956 (Acari: Oribatida: Galumnidae). *Ann. Zool.*, 57 (4): 841-850. <https://doi.org/10.3161/000345407783742051>
- Seniczak S. 1972. A method of cultivation of mites in glass cultivation tubes with asbestous bottoms. *Pol. J. Soil Sci.*, 5: 127-132.
- Seniczak S. 1975. Revision of the family Oppidae Grandjean 1953 (Acarina Oribatei). *Acarologia*, 17: 331-345.
- Shaladybina E.S. 1969b. The post-embryonic development of *Zetomimus furcatus* (Pearce et Warb.), 1905 (Oribatei, Ceratozetoidea). *Uchonyye zapiski Gorkovskogo gos. Ped. Insta. Ser. Biol.* 99: 40-52
- Shaladybina E.S. 1969a. The oribatid mites of superfamily Ceratozetoidea (their morphology, biology, systematization and a role in epizootic anoplocephalidose) [Phd Thesis] Moscow: pp 708
- Shereef G.M. 1976. Biology of two Oribatid species in Giza region. *Acarologia*, 18 (1): 171-173.
- Shereef G.M. 1972. Observations on Oribatid mites in laboratory cultures. *Acarologia*, 14 (2): 282-291.
- Siepel H. 1994. Life-history tactics of soil microarthropods. *Biol. Fertil. Soils*, 18: 263-278. <https://doi.org/10.1007/BF00570628>
- Subías L.S. 2021. Listado sistemático, sinónimo y biogeográfico de los ácaros oribátidos (Acariformes: Oribatida) del mundo (excepto fósiles). Online version accessed in March 2021, 605 pp.
- Syamjith K. P., Ramani N. 2013. Biology of the oribatid mite *Acrotrititia clavata* (Märkel, 1964) from the mangrove ecosystems of North Kerala, India. *Acarol. Stud.*, 2(2): 59-68. <https://doi.org/10.47121/acarolstud.669572>
- Søvik G., Leinaas H.P. 2003. Long life cycle and high adult survival in an arctic population of the mite *Ameronothrus lineatus* (Acari, Oribatida) from Svalbard. *Polar Biol.*, 26: 500-508. <https://doi.org/10.1007/s00300-003-0510-3>
- Tiunov, A. V., Scheu, S. 2005. Arbuscular mycorrhiza and Collembola interact in affecting community composition of saprotrophic microfungi. *Oecologia*, 142: 636-642. <https://doi.org/10.1007/s00442-004-1758-1>
- Uvarov A.V. 2003. Effects of diurnal temperature fluctuations on population responses of forest floor mites. *Pedobiologia*. 47: 331-339. <https://doi.org/10.1078/0031-4056-00197>
- Visser, S. (1971). Ecology of the fungal populations of *Populus tremuloides* litter. Msc thesis, University of Calgary. The University of Calgary, Calgary, Alberta. 104 p.
- Walter D. E., Proctor H. C. 1999. Mites: ecology, evolution, and behaviour. Springer. <https://doi.org/10.1007/978-94-007-7164-2>
- Weigmann G. 1975. Labor- und Freilanduntersuchungen zur Generationsdauern von Oribatiden (Acari: Oribatei). *Pedobiologia*. 15: 133-148.
- Woodring J. P., Cook E .F. 1962. The biology of *Ceratozetes cisalpinus* Berlese, *Schelioribates laevigatus* Koch, and *Oppia neerlandica* Oudemans (Oribatei), with a description of all stages. *Acarologia*, 4(1): 101-137.