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RESEARCH ARTICLE

# Foraging ecology and evaluation of pollination potential of native pollinators of Chayote in Tamil Nadu, India

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**Abstract**

Chayote, *Sechium edule* (Swartz) is cultivated throughout tropical and subtropical regions of the world as an important vegetable crop. The chayote flowers are monoecious, produce separate male and female flowers at different internodes within the same plant. Chayote crop relies on pollinators, mainly bees and other insects like butterflies, wasps and beetles for successful fruit production. The reduction in the service provided by the pollinators results in low fruit set and inferior quality of fruits. Many domesticated bee colonies are required to provide complete pollination services if native pollinators are deficient in Chayote cropping system. An experiment was conducted in 2024 at the farmers' field at Karumandurai in Salem district to compare the foraging activity and pollination efficiency of native dominant pollinators and domesticated pollinators. The results revealed that the foraging activity of *Apis cerana indica* (Fabricius) began at 0600 hr and ceased by 1400 hr. *Tetragonula iridipennis* (Smith) commences foraging at 0800 hr and stops it by 1500 hr. *T. iridipennis* spent an average of 26.2 sec in male flowers and 166.0 sec in female flowers, while *A. cerana indica* spent less time per flower with 9.7 sec in male flowers and 13.8 sec in female flowers. The maximum fruit set of 24.71 fruits/plant was obtained in a stingless bee pollination plot followed by an open pollination plot (24.42 fruits/plant). The pollinator exclusion plot (control) recorded no fruit set.

**Keywords:** Chayote; foraging activity; pollination; *T. iridipennis*; yield

## Introduction

Bees play a crucial role in sustaining native plant populations and supporting food production for both humans and animals by delivering vital ecosystem services through pollination (1). The pollination success largely depends on the number of pollinating insects and their functional diversity, including different active periods and variation in pollen transfer to stigma. Insect pollinators and flowering plants share a mutually beneficial relationship, where nectar and pollen serve as food for the pollinators (2, 3). Pollinators transfer pollen from the anthers to the stigmas, leading to fertilization (4). This interaction is particularly valuable for self-incompatible plants, as it promotes successful pollination (5). The essential role of pollinators, such as solitary bees and honeybees in boosting crop yields across 41 global agricultural systems was reported in previous studies (6). Over the last twenty years, there has been an enhanced interest in pollinators and pollination ecology, driven partly by worries about decline in pollinator populations and diversity (7).

As the world's population rises, it is imperative to comprehend the pollination requirements for crops to enhance the yield (8). Cucurbits hold significant economic value for smallholder farmers, especially in Asia. In 2016, the global farm gate value of cucurbits and melons reached USD 94 billion (9). The flowers of cucurbits are usually monoecious, producing male and female flowers separately on the same plant at different internodes. The pistillate and staminate flowers open on the same day, but the male flowers appear first, about two weeks earlier than the female flowers. Both types of flowers arise singly from different internodes. Insects are needed for pollen transfer due to their stickiness and the way they are released from the anthers. Pollen must be moved from the stamen of the male flower to the stigma of the female flower for fruit development. Cultivated cucurbits have sticky pollen grains, making wind dispersal difficult, so insect pollination occurs naturally in cucurbit plants (10).

Cucurbits are a well-known plant family often used in pollination studies (11-13). Chayote (*Sechium edule*), a member of the Cucurbitaceae family, is widely cultivated in tropical and subtropical regions across the globe. Chayote also finds uses in pharmaceutical, cosmetic and food industries. The plant is rich in essential nutrients such as minerals, dietary fibres, proteins, vitamins, carotenoids and flavonoids. chayote is increasingly recognized for its nutritional and health benefits. Despite its economic and nutritional importance, chayote cultivation faces challenges related to pollination. Chayote is a cross-pollinated plant, making it heavily dependent on insect pollinators for successful fruit production (14). Chayote crops require a pollinating agent and it is evident that this plant species relies on the local entomo-fauna and the availability of competitive food sources for these insects (15).

Chayote flowers are pollen and nectar rich and attract numerous pollinators. It is mainly pollinated by stingless bees such as *Nannotrigona perilampoides* Cresson and various species of stingless bees as well as some wasps in Brazil (16). *T. spinipes* (Fabricius) stingless bees have been noted in various crops gathering nectar and pollen without causing damage. They are regarded as significant pollinators and potentially been use as commercial pollinators (17). In areas where these other bee species are not natively found, stingless bees (Apidae: Meliponini) offer an option since they may be kept in transportable hive units and utilized for pollination services (18). Given the importance of successful pollination for fruit production, domesticated bees have been suggested as a possible solution to address the decline in native pollinator populations in several countries. The present study also aimed to evaluate the pollination potential of native stingless bee species *T.iridipennis* in chayote under Tamil Nadu conditions.

## Materials and Methods

### Study area

A field experiment was carried out in Karumandurai region of Salem District, India, situated at an elevation of 262 m above Mean Sea Level (MSL), with coordinates of 11.812848° N latitude and 78.676216° E longitude, during 2023-2024. The chayote experimental plots were maintained without any chemical sprays from the beginning of 10 % flowering stage. Two stingless bee colonies with an optimum population of 2000 bees were installed in the plot to study their pollination potential and foraging ecology in chayote.

### Data collection

The experimental plots were maintained without any chemical sprays during the flowering stage. The major pollinators on chayote were observed in five randomly selected 1m² areas during the flowering period with data recorded at intervals between 0600-0800, 0800-1000, 1000-1200, 1200-1400, 1400-1600 and 1600-1800 hr. To study the foraging behavior of major native pollinators, randomly selected flowers were marked and observed. The abundance of pollinators was calculated as the number of foragers per flower per min, while the foraging rate was recorded as the time spent by individual bee pollinators per flower per min on both male and female flowers. These observations were made using a stopwatch at weekly intervals during the peak period of pollinator activity (19).

### Evaluation of pollination potential of native pollinators

Three treatments were framed to find out the contribution of managed bee pollinator *T. iridipennis* in improving the yield of chayote. T1 - pollination exclusion (female flowers were covered with sleeve net cages at bud stage to prevent the entry of pollinators), T2 - managed bee pollination (Fig. 1) (combination of managed bee pollinator and native pollinator) and T3 - Open pollination (native pollinators) with seven replications. Observations were recorded at 15-day interval in randomly selected five plants for each replication from 5 flowers/plant marked.

**Fig. 1.** Domesticated *T. iridipennis* colony in chayote field.

### Pollination Efficiency Index (PEI)

The PEI was studied for dominant native pollinator *Apis cerana indica* and managed bee pollinator *T. iridipennis*. Loose pollen grains were counted by capturing foraging bees in the field during peak foraging hours, between 09:00 and 12:00, using a sweep net. The bees were transferred to a glass vial containing 70 % alcohol and shaken vigorously to dislodge the pollen grains from their bodies. The total volume was adjusted to 5 mL. From this 0.01 mL sample was taken and examined under a microscope using a haemocytometer. This process was repeated five times and the total number of pollen grains in the 5 mL solution was calculated (20).

PEI = No. of loose pollen grains on the body × foraging rate × abundance of pollinators on chayote. (Eqn. 1)

### Pollination effectiveness

Pollination effectiveness was measured by fruit set, calculated by

$$\text{Fruit set} = \frac{\text{Number of flowers that produce fruit}}{\text{Total number observed flowers}} \times 100 \quad \text{(Eqn. 2)}$$

### Yield parameters

The number of fruits on tagged plants were counted and a random sample of ten fruits from these tagged plants weighed using a weighing balance and their weights were noted. Fruits from each tagged plant were harvested and weighed and total yield calculated per hectare (21).

## Results

### Foraging ecology of *T. iridipennis* and *A. cerana indica* in chayote

The results of peak foraging activity of *T. iridipennis* and *A. cerana indica* are presented in Fig. 2. The onset and end of foraging activity of pollinators vary in time. The foraging activity of *A. cerana indica* began at 0600 hr and ceased by 1400 hr. *T. iridipennis* commences foraging at 0800 hr and stopped it by 1500 hr. Peak foraging activity for *T. iridipennis* was noticed between 1100-1200 hr, with 0.55 bees per flower per min, with gradual decline in activity after 1400 hr (Fig. 2), whereas *A. cerana indica* showed peak foraging activity earlier in the day, between 0900-1100 hr, with 0.45 bees per flower per min and with no activity after 1400 hr (Fig. 2).

Pollinating insects of *Sechium edule* were classified into primary and secondary according to their abundance and effectiveness as pollen insect collectors. The present study compared the abundance, foraging behaviour and pollination efficiency of managed bee species *T. iridipennis* and native pollinator *A. cerana indica* in chayote flowers. The results indicated that *T. iridipennis* showed a higher abundance, especially in male flowers, with an average visitation rate of 0.55 bees per flower per min compared to 0.35 in female flowers. On the 60th day of flowering, *T. iridipennis* reached maximum activity in male flowers with 0.90 bees per flower per min, while the peak in female flowers was 0.60 bees per flower per min on the 60th day. The lowest visitation for *T. iridipennis* was recorded on the 15th day, with 0.20 and 0.10 bees per min in male and female flowers, respectively (Table 1). The native primary pollinator *A. cerana indica* exhibited an average abundance of 0.48 bees per min in male flower and 0.33 in female flowers. The highest activity of 0.60 bees per flower per min in male flowers occurred on 15th day, while in female flowers, the maximum activity of 0.40 bees per flower per min was observed on both 15th and 30th day (Table 2). These findings exhibit the floral constancy and floral fidelity behaviour of *T. iridipennis* on chayote flower.

Foraging time spent per flower also differed significantly

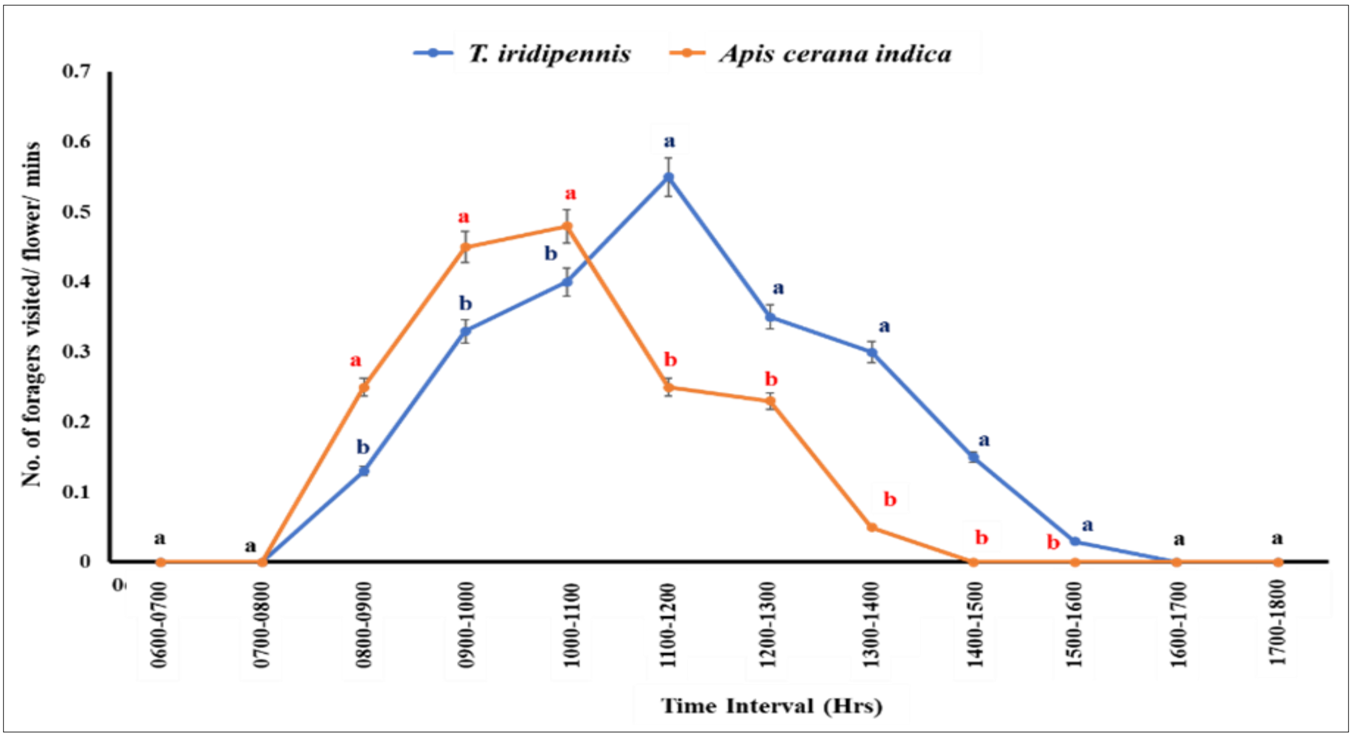


**Fig. 2.** Peak foraging activity of *A. cerana indica* and *T. iridipennis*.

**Table 1.** Abundance of *T.iridipennis* in chayote flower

| | No. of foragers/flower/ min ± S.D | | | | |
|---|---|---|---|---|---|
| | **15th day** | **30th day** | **45th day** | **60th day** | **Mean** |
| Male flower | 0.20±0.21 | 0.30±0.24 | 0.80±0.21 | 0.90±0.28 | 0.55 |
| Female flower | 0.10±0.15 | 0.20±0.21 | 0.50±0.26 | 0.60±0.25 | 0.35 |

**Note:** *Mean of 10 plant observations; SD: Standard Deviation

**Table 2.** Abundance of *A. cerana indica* in chayote flower

| | No. of foragers/flower/ min ± S.D | | | | |
|---|---|---|---|---|---|
| **Time interval** | **15th day** | **30th day** | **45th day** | **60th day** | **Mean** |
| Male flower | 0.60±0.42 | 0.40±0.25 | 0.50±0.35 | 0.40±0.34 | 0.48 |
| Female flower | 0.40±0.25 | 0.40±0.25 | 0.20±0.21 | 0.30±0.24 | 0.33 |

**Note:** *Mean of 10 plant observations; SD: Standard Deviation between the two species. *T. iridipennis* spent an average of 26.2 sec in male flowers and 166.0 sec in female flowers, with the longest flower handling time 27.1 sec recorded on the 60th day in male flowers and 197.9 sec in female flowers on 15th day (Table 3). In contrary *A. cerana indica* spent less time per flower with 9.7 sec in male flowers and 13.8 sec in female flowers. The longest foraging period of 10.1 sec in male flowers on recorded 15th day and 16.6 sec in female flowers on 60th day (Table 4).

## Pollination Efficiency Index (PEI)

PEI was higher for *T. iridipennis*, calculated at 40, 911, 750, compared to *A. cerana indica*, which had a PEI of 21, 184, 800. The results showed that *T. iridipennis* emerged as the more effective pollinator in chayote, contributing to a higher pollination success rate compared to *A. cerana indica* (Table 5).

Pollination potential of managed bee pollinator, *T. iridipennis* in Tamil Nadu: The results on the effect of different modes of pollination are presented in Table 6. The observation recorded from a total of 175 female chayote flowers representing seven replications, exhibited fertilization of 173 flowers (98.85 %) in managed bee pollination plot, while 171 flowers (97.71 %) were fertilized in open pollination plot. The observations have shown that the maximum fruit set of 24.71 fruits/plant obtained in stingless bee pollination plot followed by open pollination plot (24.42 fruits/plant). The pollinator exclusion plot (control) recorded no fruit set (Fig. 3). The average individual fruit weight obtained was higher (314.1 g/ fruit) in bee pollination plots than open pollination plots (302.6 g/fruit). These findings confirmed the pollination potential and efficiency of *T. iridipennis* as primary pollinator in chayote. The abundance and long foraging time of *T. iridipennis* ensured adequate pollination in the need of chayote flowers. The stigma is most receptive to pollen in the morning. Consequently, fruits harvested from bee-pollinated plots weigh 3.8 % more than those from open-pollinated plots. A 4.19 % higher fruit yield of 32.44 t/ha from bee pollination plots compared to open pollination plots (31.13 t/ha) was recorded.

**Table 3.** Foraging activity of *T. iridipennis* in chayote flowers

| | Time spent by a forager/flower/min in sec ± SD | | | | |
|---|---|---|---|---|---|
| | **15th day** | **30th day** | **45th day** | **60th day** | **Mean** |
| Male flower | 25.10±5.53 | 26.27±4.85 | 26.16±24.49 | 27.10±4.38 | 26.1 |
| Female flower | 197.86±27.16 | 151.78±25.74 | 163.27±24.35 | 151.11±14.46 | 166.0 |

**Note:** *Mean of 5 plant observations; SD: Standard Deviation

**Table 4.** Foraging activity of *A. cerana indica* in chayote flowers

| | Time spent by a forager/flower/min in sec ± SD | | | | |
|---|---|---|---|---|---|
| **Time interval** | **15th day** | **30th day** | **45th day** | **60th day** | **Mean** |
| Male flower | 10.00±2.80 | 10.14±1.05 | 9.86±1.25 | 8.75±1.05 | 9.7 |
| Female flower | 11.78±2.02 | 13.38±1.93 | 13.62±1.94 | 16.61±2.16 | 13.8 |

**Note:** *Mean of 5 plant observations; SD: Standard Deviation

**Table 5.** Pollination efficiency index of *T. iridipennis* and *A. cerana indica* in chayote

| Bee species | Abundance (No. of foragers/min) | Foraging rate (Foraging activity in flower /sec) | Number of loose pollen grains on the body* | Pollination index (Abundance × Foraging rate × Loose pollen grains) |
|---|---|---|---|---|
| *T. iridipennis* | 0.55 | 26.1 | 2850000 | 40911750 |
| *A. cerana indica* | 0.48 | 9.7 | 4550000 | 21184800 |

**Note:** *Mean of five observations under stereo zoom microscope

**Table 6.** Effect of *T. iridipennis* bee managed hive on the pollination and yield of chayote

| Modes of pollination | No. of female flowers observed | No. of flowers fertilised | No. of fruits / plants | Percent increase in fruit set | Fruit weight (g) | Percent increase in fruit weight | Yield of 5 plants (kg) | Yield (t/ha) | Percent increase in yield (t/ha) |
|---|---|---|---|---|---|---|---|---|---|
| Bee pollination (*T.iridipennis*) | 175 | 173 | 24.71 (5.02)[a] | 1.17 | 314.14 (17.73)[a] | 3.82 | 197.99 (14.08)[a] | 32.44 | 4.19 |
| Open pollinated condition | 175 | 171 | 24.42 (4.99)[a] | | 302.57 (17.40)[b] | - | 190.8 (13.83)[b] | 31.13 | - |
| Pollinator exclusion | 175 | | 0.00 (0.70)[b] | | 0.00 (0.70)[b] | - | 0 (0.70)[c] | 0 | - |
| S.E (d) | | | 0.023 | | 0.168 | - | 0.031 | - | - |
| C.D. (P=0.05) | | | 0.050 | | 0.353 | - | 0.093 | - | - |

**Note:** *Mean of five observations, figures in parentheses are √ (x+0.5) (square root) transformed values. In columns, means followed by alphabet are significantly different at 5 % level LSD

**Fig. 3.** Pollination exclusion in chayote flower.

## Discussion

The foraging behavior and pollination efficiency of *T. iridipennis* and *A. cerana indica* provide important insights into their role in chayote pollination. Both species demonstrated distinct foraging patterns, with *A. cerana indica* starting its foraging activity earlier, at 0600 hr and ceasing by 1400 hrs, whereas *T. iridipennis* commenced foraging later, at 0800 hr and continued until 1500 hr. This temporal variation in foraging coincides with nectar production in chayote flowers, which peaks between 0800 and 1300 hr (22), thus explaining the overlap in foraging times observed for these species. Chayote pollinators, particularly *T. iridipennis*, were most active between 0730 and 1430 hr in earlier studies (23). The present study confirms these findings, with *T. iridipennis* showing peak foraging activity between 1100-1200 hr at a rate of 0.55 bees per flower per min, while *A. cerana indica* peaked earlier, between 0900-1100 hr, with a rate of 0.45 bees per flower per min. Similar observations were made in previous research studies, where chayote pollinators exhibited their highest activity between 0900 and 1100 hr in Karnataka (24).

One of the key findings was that *T. iridipennis* showed a higher abundance and foraging rate, particularly in male flowers, where it averaged 0.55 bees per flower per min compared to 0.35 in female flowers. On the $60^{th}$ day of flowering, the peak foraging activity in male flowers reached 0.90 bees per min, suggesting the species' preference for male flowers, which are richer in pollen. In contrast, *A. cerana indica* exhibited lower overall foraging rates, with an average of 0.48 bees per min in male flowers and 0.33 in female flowers. Similar peak foraging activity for *A. cerana indica* between 0900 and 1100 hrs was reported in earlier studies (25), which aligns with the findings in this study. It was noticed that the stingless bee, *Trigona spinipes* (Fabricius) was frequent and constant pollinator in chayote flowers between 0800 and 1300 hrs in Mexico (15). Additionally, the importance of *A. cerana indica* and *Tetragonula* species in pollinating cucurbitaceae was emphasized in earlier studies (26, 27), further supporting the findings of this study.

The differences in foraging time between the two species were also notable. *T. iridipennis* spent significantly more time per flower, particularly on female flowers, with an average of 166.0 sec compared to *A. cerana indica*, which spent only 13.8 sec. This extended foraging time likely contributes to *T. iridipennis*' higher pollination efficiency. These findings are consistent with earlier research works (28-30), which indicated that the plant traits of nectar, pollen productivity and the foraging traits of pollinators can also influence the time spent by bees on handling the flowers (28). *T. laeviceps* also exhibit efficient flower handling time and a high visitation rate through better adaptation to newer environment. These bees adjust to local food sources and modify their foraging patterns to avoid competition from larger, that also visit flowers (Fig. 4).

The PEI calculated in this study further supports the greater effectiveness of *T. iridipennis* as a pollinator. *T. iridipennis* had a PEI of 40, 911, 750 which was significantly higher than the PEI of 21, 184, 800 for *A. cerana indica*. However, *T. iridipennis* had 2850000 loose pollen grains on its body compared to 4550000 on *A. cerana indica*. The increasing the amount of pollen on pistillate flower stigmas led to a higher number of fruits per plant in four melon cultivars and two non-parthenocarpic cucumber varieties over two growing seasons, along with improved seed set and germination outcomes was reported in previous scientific investigations (31). Despite carrying more pollen grains, *A. cerana indica*'s shorter foraging duration and lower abundance limited its efficiency. In contrast, the higher foraging rate and longer flower handling time of *T. iridipennis*, particularly in female flowers, led to greater pollination success.

The potential for *T. iridipennis* to enhance fruit set and yield in chayote cultivation is demonstrated by the results of the managed pollination plots, where a fertilization rate of 98.85 % was recorded, compared to 97.71 % in open pollination plots. The stingless bee pollination plot also yielded more fruits per plant (24.71 fruits/plant) and larger fruit weights (314.1 g/fruit) compared to open pollination plots (302.6 g/fruit). These results support the earlier findings (32) and suggested that although there is less receptive surface on the stigma with each successive visit, multiple bee visits per flower (ranging from 1 to 20) increase fruit set as well as the average number of seeds per fruit. This increase in pollination activity ultimately leads to a higher yield. Additionally, fruits from bee-pollinated plots weighed 3.8 % more than those from open-pollinated plots, with a 4.19 % higher fruit yield overall. Improved fruit yield in cucurbits was observed when natural pollination was supplemented by bee pollination in previous scientific experiments (33). The higher fruit set, individual fruit weight and yield in bee-pollinated plots further demonstrate the potential for *T. iridipennis* to enhance agricultural productivity through improved pollination services. These findings confirm the role of *T. iridipennis* as a primary pollinator for chayote and highlight the advantages of managed pollination over natural pollination alone.

***T. iridipennis* on a male chayote flower**

***T. iridipennis* on a female chayote flower**

***Apis cerana indica* on a male chayote flower**

***Apis cerana indica* on a female chayote flower**

**Fig. 4.** Foraging activity of *A. cerana indica* and *T. iridipennis*.

## Conclusion

Pollination services provided by insects are an important input in agriculture with extensive economic consequences. Although wild pollinators can provide pollination services to crops such as cucurbits, they normally have low populations in field and cannot meet pollination demand adequately. Therefore, the introduction of efficient managed bee pollinators will improve the productivity and quality of crops. The role of stingless bee *T. iridipennis* pollination in increasing the fruit weight of chayote is more evidenced from this study with higher PEI and better foraging traits than *A. cerana indica*. Stingless bees not only improve the fruit set but also enhance the quality and weight of the fruits by ensuring adequate and efficient pollination.

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## Authors' contributions

BM conducted the fieldwork, data analysis and data interpretation. PAS performed the taxonomy work as well as reviewed the paper for editing and grammatical errors and corrections. VRS, SRV and MV reviewed the paper for all the corrections and improvement.

## Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interest to declare.

**Ethical issues:** None

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