

## Bee or beetle: A review on the pollination biology of bottle gourd (*Lagenaria siceraria* (Molina) Standley)

Pavan Kumar, Anil Jakhar, Ankit Saini, Priyanka

Department of entomology, ccs haryana agricultural university, hisar, Haryana, India

### Abstract

Bottle gourd is a multipurpose cucurbit with monoecious, crepuscular and nocturnal habit of anthesis. Studies on the pollination biology of bottle gourd identified *Epuraea motschulskyi*, *Nesidiocoris tenuis*, and *Aulacophora foveicollis* as the most abundant floral visitors. Among the observed species, *Apis mellifera* and *Hippotion celerio* demonstrated the highest foraging speed and rate. Controlled pollination experiments showed that hand pollination and open pollination with attractants (citral-A and citral-B) significantly enhanced fruit set percentage, fruit length, and fruit weight.

**Keywords:** Bottle gourd, abundance, foraging rate, foraging speed

### Introduction

In evolution, living organisms continuously adapt their genetic makeup to overcome challenges posed by both biotic and abiotic factors [23]. These adaptive traits become encoded in the genetic material of the parent organism and are transmitted to their offspring during reproduction through chromosomal inheritance [7]. Consequently, reproduction is fundamental to both the survival and evolutionary progression of species [2]. While many organisms reproduce through the union of two opposite sexes, a process known as fertilisation, this presents a unique challenge for immobile organisms like plants. To facilitate fertilisation, plants rely on external agents to transfer pollen from male (staminate) to female (pistillate) floral parts, a process known as pollination.

In cross-pollinated plants, wind, water, and animals serve as pollination vectors [22]. Among these, animal-mediated pollination plays a particularly crucial role, accounting for approximately one-third of the human diet, facilitating the pollination of around 87.5% of wild flowering plants (about 308,000 species), supporting 85% of crops consumed by humans and traded in the global economy, and contributing to 35% of total global crop production [19]. Among animals, insects play a dominant role in flower visitation, with an estimated 141,604 species of Lepidoptera, 77,300 of Coleoptera, 70,117 of Hymenoptera, 54,417 of Diptera, 1,466 of Thysanoptera, 1,193 of Orthoptera, 1,036 of

Hemiptera, 407 of Collembola, 366 of Blattodea, 293 of Neuroptera, 144 of Trichoptera, 76 of Mecoptera, 57 of Psocoptera, 37 of Plecoptera, and 20 species of Dermaptera reported to visit flowers [26]. Despite the vast number of insect floral visitors, only a limited number are effective pollinators for specific plant species. Many insects consume pollen and nectar without making a significant contribution to the pollination process [13, 3].

Bottle gourd is recognised as a highly adaptable member of the cucurbit family. Male (staminate) flowers (Fig. 1) usually begin to develop around 55 to 59 days after planting and are distinguished by the presence of five green sepals, five white petals, and three fused staminal lobes. In comparison, female (pistillate) flowers (Fig. 1) appear approximately 14 to 28 days later, featuring five green sepals, five white petals, and three united pistil lobes situated on an inferior ovary. Studies suggest that the flowering behaviour of bottle gourd, including crepuscular and nocturnal anthesis, varies with environmental conditions, particularly temperature. The plant is monoecious and self-compatible, but it heavily relies on cross-pollination for optimal reproduction. Additionally, due to the production of large, sticky pollen grains that cannot be carried by wind, bottle gourd depends almost entirely on animals, especially insect pollinators, to ensure successful fertilisation [8].



**Fig. 1:** Staminate and Pistillate flowers of bottle gourd

Indeed, beyond floral colour and scent [11], several other factors influence whether an insect visitor serves as an effective pollinator for a particular plant species. These include the size and shape of petals, which provide a suitable landing platform [18]; the distance between the floral surface and the rewards (nectar and pollen), which must be easily accessible to the insect's mouthparts [4]; and the chemical composition of nectar and pollen, which must fulfill the nutritional needs of the insect [27]. Other important factors include the synchronization between floral anthesis, the insect's activity period, and the peak stigmatic receptivity; the time spent collecting floral rewards (foraging speed); the number of flowers visited per unit time (foraging rate); the number of pollen grains deposited per visit on the stigma; and the overall pollination efficiency index of the insect visitor [21, 12]. In essence, an insect will act as an efficient pollinator only if these conditions are favorable; otherwise, it may prefer to forage on other floral species. Therefore, recognizing the importance of these ecological factors in achieving effective pollination, the present review focuses on the abundance, foraging speed, and foraging rate of insect floral visitors of bottle gourd.

## Abundance

Studies on the percentage relative abundance of insect floral visitors to bottle gourd [25, 9, 16, 14] have shown that *Epuraea motschulskyi* is the most dominant species, accounting for 72.04% of the total insect visitors. It is followed by *Nesidiocoris tenuis* (37.65%), *Aulacophora foveicollis* (26.96%), *Diaphania indica* (19.92%), *Hippotion celerio* (18.03%), *Arthroschista hilaralis* (17.27%), *Bactrocera cucurbitae* (12.05%), and *Anadevidia peponis* (10.63%). In addition to these, several other insect species were observed visiting bottle gourd flowers, although their relative abundances were below 10% (Table 1).

Furthermore, a study by Rima (2017) [20] on the abundance of insect floral visitors to bottle gourd, using the parameter of the number of insect species visiting flowers within a one-square-meter area over a 10-minute interval, revealed that *Formica* sp. had the highest mean abundance, with 9.46 individuals/m<sup>2</sup>/10 minutes. Additionally, Manju *et al.* (2022) [9] conducted a similar study using the parameter of the number of insect species visiting bottle gourd flowers within a one-square-meter area over 5 minutes. The results showed that *Epuraea motschulskyi* was the most abundant, with 15.88 beetles/m<sup>2</sup>/5 minutes (Table. 1).

**Table 1:** Abundance of insect floral visitors to the bottle gourd

Species	%Relative abundance of species	Reference
<i>Epuraea (Haptoncus) motschulskyi</i> (Reitter)	72.04 31.76 12.24	Manju <i>et al.</i> , 2022 [9] Padhiyar and Patel, 2021 [14] Prajapati <i>et al.</i> , 2021 [16]
<i>Nesidiocoris tenuis</i> (Reuter, 1895)	37.65 22.61 17.00	Padhiyar and Patel, 2021 [14] Manju <i>et al.</i> , 2022 [9] Prajapati <i>et al.</i> , 2021 [16]
<i>Aulacophora foveicollis</i> (Lucas, 1849)	26.9 9.41 7.60 0.83	Prajapati <i>et al.</i> , 2021 [16] Padhiyar and Patel, 2021 [14] Subhakar and Sridevi, 2015 [25] Manju <i>et al.</i> , 2022 [9]
<i>Diaphania indica</i> (Saunders, 1851)	19.92 4.71 0.63 0.17	Subhakar and Sridevi, 2015 [25] Padhiyar and Patel, 2021 [14] Prajapati <i>et al.</i> , 2021 [16] Manju <i>et al.</i> , 2022 [9]
<i>Hippotion celerio</i> (Linnaeus, 1758)	18.03 4.71 0.47	Subhakar and Sridevi, 2015 [25] Padhiyar and Patel, 2021 [14] Manju <i>et al.</i> , 2022 [9]
<i>Arthroschista hilaralis</i> (Walker, 1859)	17.27	Subhakar and Sridevi, 2015 [25]
<i>Bactrocera cucurbitae</i> (Coquillett, 1899)	12.05	Prajapati <i>et al.</i> , 2021 [16]
<i>Anadevidia peponis</i> (Fabricius, 1775)	10.63 3.52	Subhakar and Sridevi, 2015 [25] Padhiyar and Patel, 2021 [14]
<i>Hieroglyphus banian</i> (Fabricius, 1798)	8.60	Subhakar and Sridevi, 2015 [25]
<i>Oecophylla smaragdina</i> (Fabricius, 1775)	7.33	Subhakar and Sridevi, 2015 [25]
<i>Cheilomenes sexmaculata</i> (Fabricius, 1781)	7.26	Prajapati <i>et al.</i> , 2021 [16]
<i>Mantis religiosa</i> (Linnaeus, 1758)	6.40	Subhakar and Sridevi, 2015 [25]
<i>Apis dorsata</i> Fabricius, 1793	5.82	Prajapati <i>et al.</i> , 2021 [16]
<i>Agrilus convolvuli</i> (Linnaeus, 1758)	4.71	Padhiyar and Patel, 2021 [14]
<i>Camponotus compressus</i> (Fabricius, 1787)	4.41	Prajapati <i>et al.</i> , 2021 [16]
<i>Nezara viridula</i> (Linnaeus, 1758)	3.69	Prajapati <i>et al.</i> , 2021 [16]
<i>Coccinella transversalis</i> Fabricius, 1781	3.39	Prajapati <i>et al.</i> , 2021 [16]
<i>Phaneroptera falcata</i> (Poda, 1761)	2.35	Padhiyar and Patel, 2021 [14]
<i>Pieris brassicae</i> (Linnaeus, 1758)	2.27	Subhakar and Sridevi, 2015 [25]
<i>Apis cerana</i> Fabricius, 1793	2.03 1.82	Manju <i>et al.</i> , 2022 [9] Prajapati <i>et al.</i> , 2021 [16]
Abundance (no./m <sup>2</sup> /10 minutes)		
<i>Formica</i> sp.	9.46	Rima, 2017 [20]
Abundance (no./m <sup>2</sup> /5 minutes)		
<i>Epuraea (Haptoncus) motschulskyi</i> (Reitter)	15.88	Manju <i>et al.</i> , 2022 [9]
<i>Nesidiocoris tenuis</i> (Reuter, 1895)	4.98	Manju <i>et al.</i> , 2022 [9]

The dominant visitor, *Epuraea motschulskyi*, commonly referred to as the sap beetle, belongs to the subfamily Nitidulinae. It is a small insect, typically ranging from 2 to 5 mm in length, with an oval and slightly elongated body featuring a convex upper surface. Its colouration varies from dark to light brown, and it possesses a glossy exoskeleton (Fig. 2). This beetle is typically found in environments rich in organic matter, especially where decaying plant material is present. It primarily feeds on fermented plant substances and is frequently drawn to decomposing fruits, leaves, plant

debris, and compost heaps. In bottle gourd fields, *E. motschulskyi* is especially attracted to overripe fruits, leaf litter, and compost in and around the crop area. Females lay their eggs in moist organic material, including fruit cracks and within floral tissues. The emerging larvae consume plant sap, decaying material, floral parts, and mature fruits. Their feeding activity includes tunnelling into the soft tissues of the fruit, which facilitates pathogen entry and accelerates spoilage. In their adult stage, these beetles feed exclusively on nectar and pollen. While moving from flower

to flower in search of food, they inadvertently assist in pollination [1].

The role of beetles in pollination was demonstrated by Halder *et al.* (2024) [6] in pointed gourd (*Trichosanthes dioica* Roxb.). Initially, due to the beetle's small size, confirmation was needed to determine whether it could carry pollen grains. To investigate this, beetles were collected from both staminate (male) and pistillate (female) flowers and examined under a NIKON SMZ-10A stereo microscope. Specific body parts, including the elytra, antennae, legs, and other regions, were closely inspected for the presence of pollen. Sticky pollen clusters were observed adhering to antennal segments, the pterothorax, elytra, pygidium, and tarsal segments. The identity of these pollen grains as those of the pointed gourd was confirmed using a

Leica DMi8 microscope (Leica Microsystems, Wetzlar, Germany) (Halder *et al.*, 2024) [6].

Further validation came from a controlled pollination experiment. Male and female flower-bearing branches were placed inside a plastic container (35 cm in diameter and 33 cm in height), which was sealed to prevent entry by any other insects. Different numbers of beetles, 5, 10, 15, 20, and 25, were released into the container through a small, manually operable opening. The highest fruit set (30.45%) occurred with the release of 20 beetles, while the lowest (5.26%) was recorded with just 5 beetles. After ten days, flowers pollinated by beetles produced fruits with superior quality compared to those from hand pollination, including the longest fruit length (6.88 cm), highest fruit weight (22.63 g), and greatest fruit width (2.83 cm) (Halder *et al.*, 2024) [6].



Fig. 2: *Epuraea motschulskyi* on bottle gourd flower

The dominant visitors, such as *Nesidiocoris tenuis* and *Aulacophora foveicollis* (Fig. 3), were previously classified as pests [17] where *Nesidiocoris tenuis* caused fruit damage and *Aulacophora foveicollis* caused foliar damage. Apart from this, since the following insects visit the staminate and pistillate flowers of the bottle gourd more often, future studies need to know whether they are involved in pollination or not. Furthermore, bottle gourd flowers are

mostly open at night, when many lepidopteran insects like moths and hawk moths visit the flowers [8]. Hence, by considering the correlation between the nocturnal blooming of bottle gourd and nocturnal lepidopteran visits to bottle gourd flowers, future studies need to be conducted on the contributions of nocturnal pollination, especially lepidopterans, in bottle gourd production.

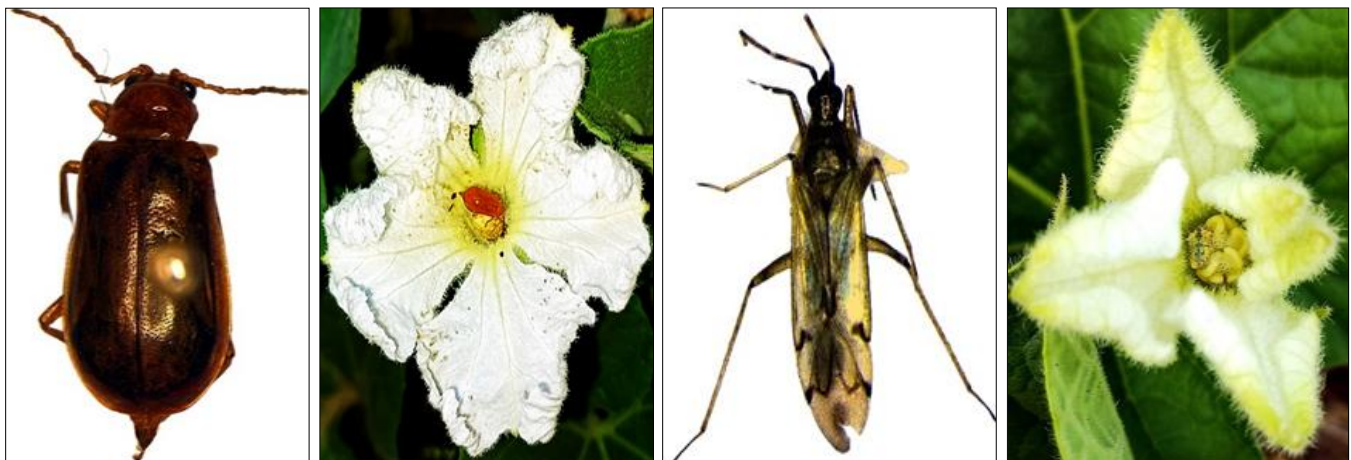


Fig. 3: *Aulacophora foveicollis* and *Nesidiocoris tenuis* on bottle gourd flower

**Foraging Speed and Foraging Rate**

Studies on the foraging speed of insect floral visitors to bottle gourd, as reported by Morimoto *et al.* (2004) [10], revealed that *Apis mellifera* (Fig. 4) exhibited the highest

foraging speed at 48.00 seconds per visit. This was followed by *Ceratina* sp. (36.00 s), *Coryna* sp. (33.50 s), *Goryra johnstoni* (32.60 s), *Anthophora* sp. (5.50 s), *Agrius convolvuli* (1.50 s), *Belenois creona* (1.00 s), and *Anthene*

*lunulate* (1.00 s). Additionally, the study also examined foraging rate, defined as the number of floral visits per day. *Hippotion celerio* recorded the highest foraging rate at 6.50 visits/day, followed by *Gorgyra johnstoni* (5.00), *Coryna*

sp. (2.00), *Anthophora* sp. (2.00), *Belenois creona* (2.00), *Apis mellifera* (2.00), *Anthene lunulate* (1.00), *Ceratina* sp. (1.00), and *Agrius convolvuli* (1.00) (Table. 2.).



Fig. 4: *Apis mellifera* on bottle gourd flowers

Table 2: Foraging speed and foraging rate of the insect floral visitors of the bottle gourd

Species	Foraging speed (seconds)	Foraging rate (no. of visits/day)	Reference
<i>Apis mellifera</i> Linnaeus, 1758	48.00	2.00	Morimoto <i>et al.</i> , 2004 <sup>[10]</sup>
<i>Gorgyra johnstoni</i> (Butler, 1894)	32.60	5.00	Morimoto <i>et al.</i> , 2004 <sup>[10]</sup>
<i>Agrius convolvuli</i> (Linnaeus, 1758)	1.50	1.00	Morimoto <i>et al.</i> , 2004 <sup>[10]</sup>
<i>Hippotion celerio</i> (Linnaeus, 1758)	3.20	6.50	Morimoto <i>et al.</i> , 2004 <sup>[10]</sup>
<i>Belenois creona</i> (Cramer, 1776)	1.00	2.00	Morimoto <i>et al.</i> , 2004 <sup>[10]</sup>
<i>Ceratina</i> sp.	36.00	1.00	Morimoto <i>et al.</i> , 2004 <sup>[10]</sup>
<i>Anthene lunulate</i> (Trimen, 1894)	1.00	1.00	Morimoto <i>et al.</i> , 2004 <sup>[10]</sup>
<i>Coryna</i> sp.	33.50	2.00	Morimoto <i>et al.</i> , 2004 <sup>[10]</sup>
<i>Anthophora</i> sp.	5.50	2.00	Morimoto <i>et al.</i> , 2004 <sup>[10]</sup>

In studies of foraging behavior, in addition to foraging speed and foraging rate, other important parameters such as the time of foraging initiation, peak foraging periods, and foraging termination should be examined, especially for domesticated bees like *Apis mellifera*, *Apis cerana*, *Apis florea*, and *Tetragonula iridipennis*. Understanding these factors will provide insights into the capacity of worker bees to pollinate flowers during a single foraging day. When combined with data on the number of pistillate flowers produced per vine and per acre, this knowledge can inform the optimal number of bee boxes required in an apiary and aid in designing controlled pollination studies. Additionally, this information is valuable for scheduling pesticide applications during the flowering period to minimize harm to pollinators. Moreover, in the case of *Apis dorsata*, tracking their flight paths after foraging termination can assist in locating their hives.

**Controlled pollination treatments**

**Pollination exclusion**

In pollination exclusion studies <sup>[15, 24]</sup>, pistillate flowers of bottle gourd were tagged and covered with paper bags before anthesis to prevent access by pollinators. As a result, all such studies reported a fruit set percentage of zero, providing strong evidence that bottle gourd is predominantly a cross-pollinated plant (Table. 3).

**Hand Pollination**

In hand pollination studies of bottle gourd <sup>[20]</sup>, pistillate flower buds were randomly tagged and covered with paper

bags. At the time of maximum stigmatic receptivity, these tagged flowers were hand-pollinated and then re-covered with paper bags. Following successful fruit set, parameters such as percentage fruit set, fruit length, and fruit weight were measured. The study reported a fruit set of 71.52%, average fruit length of 89.70 cm, and fruit weight of 2200.54 g in hand-pollinated bottle gourd flowers (Table. 3).

In practice, farmers incur additional labor costs during the blooming period to collect pollen from staminate flowers and manually dust it onto pistillate flowers. While hand pollination often results in better yields, its profitability depends on whether the market price of the produce covers the extra labor costs. If not, hand pollination becomes time-consuming and costly. Moreover, bottle gourd flowers sometimes open at night, making it challenging for farmers to perform hand pollination during those hours.

**Open Pollination**

In open pollination studies <sup>[24, 15, 20]</sup>, bottle gourd flowers were tagged and left to undergo natural pollination. Subsequently, the percentage of fruit set, fruit length, and fruit weight were measured from these tagged flowers. Srikanth *et al.* (2013) <sup>[24]</sup> reported a fruit set of 63.48%, fruit length of 43.93 cm, and fruit weight of 961.24 g. Padhiyar and Patel (2022) <sup>[15]</sup> observed a 59.67% fruit set with an average fruit weight of 1870.00 g, while Rima (2017) <sup>[20]</sup> recorded a fruit set of 60.85%, fruit length of 80.90 cm, and fruit weight of 1700.56 g under open pollination conditions (Table. 3).

**Open Pollination with Attractants**

In open pollination studies using bee attractants, the fruit set percentage, fruit length, and fruit weight were measured in bottle gourd plots treated with citral-a and citral-b during the flowering period. Srikanth *et al.* (2013) [24] reported a fruit set of 69.10%, fruit length of 47.29 cm, and fruit weight of 2130.00 g with citral-a application, while citral-b treatment resulted in a 67.40% fruit set, 47.30 cm fruit length, and 2060.00 g fruit weight (Table. 3).

In behavioral studies, beyond bee attractants, it is important to investigate the effects of ecological engineering approaches on pollination. Techniques such as chocolate-box ecology and floral stripping, where diverse flowering plants are grown alongside crops and on bunds, may enhance pollinator attraction due to increased floral diversity. Further research is also needed to assess the impact of artificially produced floral volatiles [5] on pollinator diversity, abundance, and fruit set percentage. Should these studies yield positive results, the use of floral volatile sprays with optimized formulations could become a valuable tool in pollination management.

**controlled *apis cerana indica* pollination**

In controlled pollination studies with *Apis cerana indica*, bottle gourd crops were exclusively pollinated by this species by placing bee boxes inside the crop and covering the area with mosquito netting during flowering. Using this method, Padhiyar and Patel (2022) [15] recorded a fruit set of 54.03% and an average fruit weight of 878.57 g when four *Apis cerana indica* boxes were introduced at 10% flowering (Table. 3).

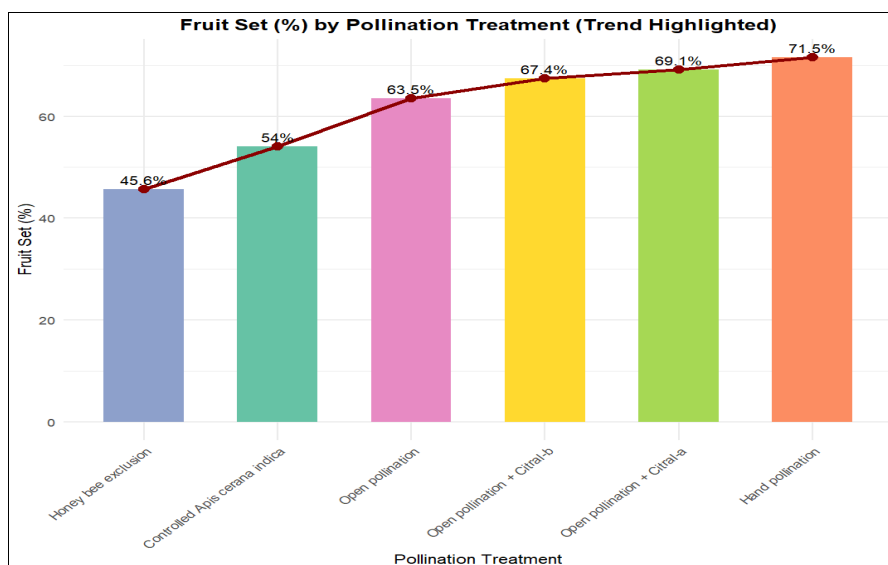
The bottle gourd (*Lagenaria siceraria*) undergoes nocturnal flowering, with blossoms typically opening in the evening and remaining receptive throughout the night, eventually closing by midday of the following day. Conversely, honey bees, especially those belonging to the genus *Apis*, are predominantly active during daylight hours, from morning to late afternoon. This misalignment between floral receptivity and pollinator activity results in limited interaction time. Although *Apis* species are generally recognized for their efficiency as pollinators, their actual role in bottle gourd pollination may be minimal under these temporal conditions. Research to date has primarily focused on *Apis cerana indica*, yet there is a need to evaluate the pollination efficiency of *Apis mellifera*, which holds significant economic importance. If proven effective under controlled conditions, incorporating *A. mellifera* into bottle gourd farming systems may offer a viable strategy for enhancing pollination outcomes and potentially increasing productivity.

**Honey Bee Pollination Exclusion**

In a honey bee exclusion experiment, Rima (2017) [20] employed 40-mesh nylon nets to cover selected bottle gourd plots, effectively preventing the entry of bees and thereby eliminating their pollination influence. Under these exclusion conditions, a fruit set of 45.65%, an average fruit length of 62.70 cm, and a mean fruit weight of 1500.40 g were observed (Table. 3). This approach serves as a useful method for quantifying the specific contributions of various pollinators to crop yield. The study also emphasised that, in addition to *Apis* species, other floral visitors play a notable role in enhancing bottle gourd productivity.

**Table 3:** Controlled pollination treatments in the bottle gourd

Pollination treatments	Fruit set (%)	Fruit length (cm)	Fruit weight (g)	References
Pollination exclusion	0.00 0.00	0.00 0.00	0.00 0.00	Padhiyar and Patel, 2022 [15] Srikanth <i>et al.</i> , 2013 [24]
Hand pollination	71.52	89.70	2200.54	Rima, 2017 [20]
Open pollination with the attractant (Citral-a)	69.10	47.29	2130.00	Srikanth <i>et al.</i> , 2013 [24]
Open pollination with the attractant (Citral-b)	67.40	47.30	2060.00	Srikanth <i>et al.</i> , 2013 [24]
Open pollination	63.48 59.67 60.85	43.93 - 80.90	961.24 1870.00 1700.56	Srikanth <i>et al.</i> , 2013 [24] Padhiyar and Patel, 2022 [15] Rima, 2017 [20]
Controlled <i>Apis cerana indica</i> pollination	54.03	-	878.57	Padhiyar and Patel, 2022 [15]
Honey bee exclusion pollination	45.65	62.70	1500.40	Rima, 2017 [20]



**Fig. 5:** Fruit set percentage in various pollination treatments

## Conclusion

Pollination in bottle gourd involves a variety of insect species, including bees, beetles, moths, and bugs, each playing a distinct role in the pollination process. Research has demonstrated that both native insect visitors and managed species such as *Apis cerana* significantly contribute to successful pollination and crop productivity. Techniques like hand pollination and the application of floral attractants have been shown to improve fruit set and yield. Moving forward, it is essential to refine these pollination methods under real-world farming conditions and to prioritise the conservation of native pollinators for long-term sustainability in bottle gourd cultivation.

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