**Review Article**

**Floral Biology and Pollination Biology of the Bottle Gourd *Lagenaria siceraria*(Molina) Standley: Insights and Implications**

**Abstract**

Pollination is vital for the survival of cross-pollinated plants, which is achieved through the use of wind, water, and animal vectors. In animals, insects are the major vectors of pollination, including cucurbitaceous crops, where the bottle gourd is monoecious with a diurnal, crepuscular, and nocturnal habit of anthesis. Furthermore, previous studies on floral visitors of bottle gourd recorded 86 insect species consisting of 23 Hymenopterans, 22 Lepidopterans, 21 Dipterans, 11 Coleopterans, 4 Hemipterans, 2 Orthopterans, and 1 each of Odonatan, Thysanopteran, and Mantodean insects visiting bottle gourd flowers, with *Epuraea motschulskyi* being the most dominant visitor. In addition, studies on foraging speed and foraging rate revealed that among the insect floral visitors, *Apis mellifera* and *Hippotion celerio* have the highest. Subsequently, in the controlled pollination treatments, hand pollination recorded superior results with the highest fruit set percentage, fruit length, and fruit weight. This paper reviews the floral biology, diversity of insect floral visitors, abundance, foraging rate, foraging speed, and controlled pollination treatments of the bottle gourd.

***Keywords:*** *pollination****,*** *bottle gourd, floral biology, insect visitors*

**1. INTRODUCTION**

The bottle gourd, *Lagenaria siceraria* (Molina) Standley is one of the multipurpose Cucurbitaceous vegetables domesticated first in Southern Africa (Zhao et al., 2024), and its tender fruits are consumed as fresh vegetables. In contrast, dried fruits are used as storage jars, containers, bowls, musical instruments, and fishing floats (Ahuja et al., 2011). Additionally, it has numerous medicinal values, like a low-calorie vegetable rich in vitamins and minerals with antianxiety, antioxidant, antiurolithiatic, anthelmintic, antihyperlipidemic, antihyperglycemic, anticancer, anti-inflammatory, immunomodulator, and hepatoprotective properties. Moreover, the fruit pulp treats stomach acidity, indigestion, ulcers, hair disorders, diabetes, hypertension, and liver ailments (Zahoor et al., 2021). In addition, the vine is used as a rootstock, and its pollen is used for breeding seedless watermelons (Ulas et al., 2019; Sugiyama et al., 2014). Despite the huge benefits of bottle gourd, in India, the crop is cultivated in an area of 193 thousand hectares with a production of 3,171 thousand metric tons and a productivity of 366 metric tons per hectare (NHB, 2021). However, poor fruit sets and low-quality fruits are the major constraints to achieving the economic yield potential in cucurbitaceous crops, including bottle gourd. These are often attributed to a lack of effective pollination. Indeed, hand pollination is usually recommended as an ad hoc measure for increasing fruit yield, but it is labor-intensive and time-consuming. Hence, a comprehensive review of the floral biology, diversity, abundance, foraging speed, foraging rate of insect floral visitors, and controlled pollination treatments of the bottle gourd was undertaken to identify the implications.

**2. Floral biology of the bottle gourd**

Bottle gourd is monoecious, self-compatible, and highly cross-pollinated, requiring a protandrous plant, where staminate and pistillate flowers appear 55 to 83 days after planting on different nodes of the same plant with a ratio of 19:1 to 23:1 (Okunlola et al., 2022). Despite the staminate flowers appearing early at 55 to 59 days after planting with a long peduncle, 5 green sepals, 5 smaller white petals, and 3 fused stamens, they last for a short time (Sugiyama et al., 2014) compared with pistillate flowers, which appear 14 to 28 days later with a short peduncle, 5 green sepals, 5 larger white petals, 3 united carpels, and an inferior ovary (Okunlola et al., 2022; Khosa and Dhatt, 2015; Sugiyama et al., 2014; Morimoto et al., 2004; Stephens et al., 1994), and the flowers exhibit crepuscular blooming such as opening in late afternoon (Sugiyama et al., 2014; Shrivastava, 1990) and mostly in the night (Okunlola et al., 2022; Nandpuri and Singh, 1967; Theis et al., 2014). However, in south Indian conditions, anthesis (flower opening) takes place between 9 AM and 2 PM with the stigma remaining receptive for 24 h before and after anthesis (Joshi and Gaur, 1971), while in north Indian conditions, stigmatic receptivity lasts for 36 h before anthesis to 60 h after anthesis (Nandpuri and Singh, 1967). Furthermore, it is estimated to have high cross-pollination ability (Tiwari and Ram, 2009), where pollen grains are large and sticky, so wind and water are not involved in pollination. Hence, it depends entirely on the animals, especially insects, for pollination and successful fruit set (Morimoto et al., 2004; Okunlola et al., 2022). However, despite the geographical variation in the anthesis of the bottle gourd, future studies need to focus on the parameters responsible for different anthesis and factors responsible for the lack of synchronization in the anthesis and foraging period of the pollinators.

**3. Diversity of insect visitors to bottle gourd flowers**

The growth, development, and reproduction of living organisms are based on the type of food materials they consume (Wu, 2022), and many arthropod insects eat nectar and pollen (Rácz et al., 2023). Pollen is a male gamete with 54.22% carbohydrates, 21.30% proteins, and 5.31% lipids. At the same time, nectar is a complex, dynamic, energy-rich fluid containing sugars, amino acids, proteins, fatty acids, salts, vitamins, secondary metabolites, and water (Nicolson, 2022).

**3.1 Hymenoptera**

Hymenopteran insects have a division of labor (Grüter, 2020), where workers are actively engaged in food collection through their chewing and lapping mouthparts, which are exclusively meant for taking floral rewards such as nectar and pollen (Basari et al., 2021), which makes them the most efficient pollinators (Khalifa et al., 2021). Furthermore, at the time of the collection of floral rewards, the pollen grains stick to the body and are deposited on the stigma when landed on pistillate flowers. Additionally, the hymenopteran legs are modified to perform the function of pollen handling and packing (Portman et al., 2019). Despite the significant role of hymenopteran insects in pollination, a comprehensive review on hymenopteran floral visitors of bottle gourd (Morimoto et al., 2004; Srikanth et al., 2013; Manju et al., 2022; Sree Latha et al., 2018; Padhiyar and Patel, 2021; Subhakar and Sridevi, 2015; Rima, 2017; Saradar et al., 2024; Prajapati et al., 2021) revealed that 23 species visited bottle gourd flowers, with 11 insect species belonging to the Apidae family, 5 to Formicidae, 3 to Halictidae, and 1 to each Megachilidae, Ichneumonidae, Vespidae, and Scoliidae (Table 1).

**3.2 Lepidoptera**

Lepidopteran insects have egg, larvae, pupae, and adult stages (Sedlacek et al., 2018). In the larval stage, many insects are phytophagous (Wang et al., 2024) with their biting and chewing mouthparts (Liu and Jiang, 2023), but in the adult stage, the mouthparts are changed into the siphoning type (Guo et al., 2018). Despite this change, adults are confined to liquid food (Lehnert et al., 2016), and nectar is one of them (He et al., 2022). Hence, during the collection of nectar from the flower, the pollen grains stick to the body and get pollinated when landed on pistillate flowers. Moreover, studies on insect visitors to bottle-gourd flowers (Subhakar and Sridevi, 2015; Morimoto et al., 2004; Padhiyar and Patel, 2021; Srikanth et al., 2013; Thapa, 2006) revealed that 22 lepidopteran species visited bottle-gourd flowers, with 8 insect species belonging to the Sphingidae family and 5 to Pieridae, 2 to each Crambidae and Lycaenidae, and 1 to each Noctuidae, Pyralidae, Papilionidae, Hesperiidae, and Erebidae (Table 1).

**3.3 Diptera**

Dipteran insects undergo complete metamorphosis with eggs, larvae, pupa, and adult stages (Courtney et al., 2017). The larval stage is known as maggot, and in the adult stage, maggots transition from chewing mouthparts with hooks and spines (Bruno et al., 2020) that tear plant and animal tissues to sponging mouthparts with proboscis, specifically designed for consuming liquid food (Lehnert et al., 2022), where many adult dipterans feed on floral rewards such as nectar and pollen (Davis et al., 2023). Despite the hardy nature of pollen grains, pollen is crushed and swallowed by placing them between hardened plates of labella, and nectar is consumed with the help of the sucking pads of the proboscis (Sarwar, 2020). Furthermore, due to the stickiness of the pollen grains and the electrostatic forces of attraction (Khan et al., 2021), the pollen gets attached to the dipteran body and deposited on the stigma when it lands on the pistillate flowers. Moreover, the dipteran body has long bristles that provide more surface area for carrying more pollen grains (Cook et al., 2020). Hence, considering the significant role of dipteran insects in pollination, previous studies (Srikanth et al., 2013; Rima, 2017; Pramanik et al., 2023; Thapa, 2006) recorded 21 dipteran species as floral visitors of the bottle gourd. Among these, 10 species belong to the Syrphidae family, 2 to each Tephritidae, Stratiomyidae, Muscidae, and Calliphoridae family, and 1 to each Micropezidae, Lauxaniidae, and Micropezidae family (Table 1).

**3.4 Coleoptera**

Coleopteran insects are phytophagous (Dedyukhin, 2015) and have biting and chewing mouthparts in the grub and adult stages (Liu and Tong, 2023). Additionally, many insects feed on floral petals, nectar, and pollen (Saravy et al., 2021; Batelka and Prokop, 2021). Due to this anthophilous nature, many coleopteran insects visit flowers and act as pollination vectors. Furthermore, previous studies (Morimoto et al., 2004; Prajapati et al., 2021; Srikanth et al., 2013; Rima, 2017; Dasgupta et al., 2018) recorded 11 coleopteran insect species visiting bottle gourd flowers, with 4 species belonging to the Chrysomelidae and Coccinellidae families and 1 to each the Meloidae, Nitidulidae, and Melolonthidae (Table 1).

**3.5 Hemiptera**

Hemipteran insects have piercing and sucking mouthparts in the nymph and adult stages. In piercing and sucking mouthparts, stylets are modified to puncture the plant tissue (Wang et al., 2020). Apart from this, some hemipteran insects also feed on floral nectar (Zhu et al., 2014), which makes the vectors of pollination (Garcia et al., 2023). Furthermore, studies on the insect visitors to bottle gourd flowers (Prajapati et al., 2021; Shrivastava, 1990; Rima, 2017) recorded 4 hemipteran species belonging to the family Pentatomidae, Pyrrhocoridae, Miridae, and Aphididae visited bottle gourd flowers (Table 1).

**3.6 Orthoptera**

Orthopteran nymphs and adults have biting and chewing mouthparts with a phytophagous nature (El Harche et al., 2024). In addition, orthopteran insects also feed on nectar and pollen, enabling them to visit flowers (Rácz et al., 2023). Furthermore, previous studies (Padhiyar and Patel, 2021; Subhakar and Sridevi, 2015) stated that *Phaneroptera falcata* of the Tettigoniidae family and *Hieroglyphus banian* of the Acrididae family visited bottle gourd flowers (Table 1).

**3.7 Thysanoptera**

Thysanopteran nymphs and adults have asymmetrical, rasping, and sucking mouthparts with plant sap as their major food (Singh and Rachana, 2020). Additionally, thrips eat pollen grains that make them visit flowers (Visschers et al., 2023). Furthermore, Rima (2017) stated that *Megalurothrips usitatus* of the Thripidae family visited bottle-gourd flowers (Table 1).

**3.8 Mantidae**

Mantodean insects have mandibulate mouthparts with predatory behavior (Gao et al., 2021). In addition, some insect species eat pollen grains. Hence, due to their pollen-feeding nature (Lanna et al., 2021), they visit flowers and act as pollination vectors. Furthermore, Subhakar and Sridevi (2015) stated that *Mantis religiosa*of the Mantidae family visited bottle gourd flowers (Table 1).

**Table 1. Insect visitors of the bottle gourd flower**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.NO** | **Scientific name** | **Family** | **Oder** | **References** |
| 1 | *Apis mellifera* Linnaeus, 1758 | Apidae | Hymenoptera | Morimoto et al., 2004 |
| 2 | *Apis dorsata* Fabricius, 1793 | Apidae | Hymenoptera | Srikanth et al., 2013 |
| 3 | *Apis cerana* Fabricius, 1793 | Apidae | Hymenoptera | Manju et al., 2022 |
| 4 | *Amegilla zonata* (Linnaeus, 1758) | Apidae | Hymenoptera | Srikanth et al., 2013 |
| 5 | *Ceratina binghami* Cockerell, 1908 | Apidae | Hymenoptera | Srikanth et al., 2013 |
| 6 | *Ceratina hieroglyphica* Smith, 1854 | Apidae | Hymenoptera | Srikanth et al., 2013 |
| 7 | *Tetragonula iridipennis* (Smith, 1854) | Apidae | Hymenoptera | Sree Latha et al., 2018 |
| 8 | *Xylocopa* sp. | Apidae | Hymenoptera | Padhiyar and Patel, 2021 |
| 9 | *Xylocopa fenestrata*(Fabricius, 1798) | Apidae | Hymenoptera | Bhardwaj et al., 2012 |
| 10 | *Xylocopa virginica*(Linnaeus, 1771) | Apidae | Hymenoptera | Bhardwaj et al., 2012 |
| 11 | *Anthophora* sp. | Apidae | Hymenoptera | Morimoto et al., 2004 |
| 12 | *Camponotus compressus* (Fabricius, 1787) | Formicidae | Hymenoptera | Padhiyar and Patel, 2021 |
| 13 | *Camponotus pennsylvanicus*(De Geer, 1773) | Formicidae | Hymenoptera | Alim et al., 2023 |
| 14 | *Oecophylla smaragdina* (Fabricius, 1775) | Formicidae | Hymenoptera | Subhakar and Sridevi, 2015 |
| 15 | *Formica* sp. | Formicidae | Hymenoptera | Rima, 2017 |
| 16 | *Trichomyrmex* sp. | Formicidae | Hymenoptera | Saradar et al., 2024 |
| 17 | *Nomia elliotii* (Smith, 1875) | Halictidae | Hymenoptera | Srikanth et al., 2013 |
| 18 | *Nomia iridescens* (Smith, 1857) | Halictidae | Hymenoptera | Srikanth et al., 2013 |
| 19 | *Halictus* sp. | Halictidae | Hymenoptera | Srikanth et al., 2013 |
| 20 | *Megachile (Eutricharaea)* sp. | Megachilidae | Hymenoptera | Prajapati et al., 2021 |
| 21 | *Xanthopimpla stemmator*(Thunberg, 1822) | Ichneumonidae | Hymenoptera | Bhardwaj et al., 2012 |
| 22 | *Polistes* sp**.** | Vespidae | Hymenoptera | Bhardwaj et al., 2012 |
| 23 | *Scolia* sp. | Scoliidae | Hymenoptera | Bhardwaj et al., 2012 |
| 24 | *Hippotion celerio* (Linnaeus, 1758) | Sphingidae | Lepidoptera | Morimoto et al., 2004 |
| 25 | *Agrius convolvuli* (Linnaeus, 1758) | Sphingidae | Lepidoptera | Morimoto et al., 2004 |
| 26 | *Acosmeryx shervillii*Boisduval, 1875 | Sphingidae | Lepidoptera | Lu et al., 2021 |
| 27 | *Pergesa acteus*(Cramer, 1779) | Sphingidae | Lepidoptera | Lu et al., 2021 |
| 28 | *Psilogramma discistriga*Walker, 1856 | Sphingidae | Lepidoptera | Lu et al., 2021 |
| 29 | *Psilogramma increta* (Walker, 1865) | Sphingidae | Lepidoptera | Lu et al., 2021 |
| 30 | *Theretra tibetiana*Vaglia & Haxaire, 2010 | Sphingidae | Lepidoptera | Lu et al., 2021 |
| 31 | *Theretra silhetensis*Walker, 1856 | Sphingidae | Lepidoptera | Lu et al., 2021 |
| 32 | *Pieris brassicae* (Linnaeus, 1758) | Pieridae | Lepidoptera | Subhakar and Sridevi, 2015 |
| 33 | *Belenois creona* (Cramer, 1776) | Pieridae | Lepidoptera | Morimoto et al., 2004 |
| 34 | *Eurema hecabe* (Linnaeus, 1758) | Pieridae | Lepidoptera | Padhiyar and Patel, 2021 |
| 35 | *Delias eucharis* (Drury, 1773) | Pieridae | Lepidoptera | Subhakar and Sridevi, 2015 |
| 36 | *Danaus chrysippus*(Linnaeus, 1758) | Pieridae | Lepidoptera | Srikanth et al., 2013 |
| 37 | *Spoladea recurvalis* (Fabricius, 1775) | Crambidae | Lepidoptera | Padhiyar and Patel, 2021 |
| 38 | *Diaphania indica* (Saunders, 1851) | Crambidae | Lepidoptera | Subhakar and Sridevi, 2015 |
| 39 | *Lampides boeticus*(Linnaeus, 1767) | Lycaenidae | Lepidoptera | Thapa, 2006 |
| 40 | *Anthene lunulate* (Trimen, 1894) | Lycaenidae | Lepidoptera | Morimoto et al., 2004 |
| 41 | *Anadevidia peponis* (Fabricius, 1775) | Noctuidae | Lepidoptera | Subhakar and Sridevi, 2015 |
| 42 | *Arthroschista hilaralis* (Walker, 1859) | Pyralidae | Lepidoptera | Subhakar and Sridevi, 2015 |
| 43 | *Pachliopta hector* (Linnaeus, 1758) | Papilionidae | Lepidoptera | Srikanth et al., 2013 |
| 44 | *Gorgyra johnstoni* (Butler, 1894) | Hesperiidae | Lepidoptera | Morimoto et al., 2004 |
| 45 | *Dysgonia* sp. | Erebidae | Lepidoptera | Srikanth et al., 2013 |
| 46 | *Paragus yerburiensis* Stuckenberg, 1954 | Syrphidae | Diptera | Srikanth et al., 2013 |
| 47 | *Scaeva pyrastri* (Linnaeus, 1758) | Syrphidae | Diptera | Rima, 2017 |
| 48 | *Paragus crenulatus*Thomson, 1869 | Syrphidae | Diptera | Srikanth et al., 2013 |
| 49 | *Paragus serratus*(Fabricius, 1805) | Syrphidae | Diptera | Srikanth et al., 2013 |
| 50 | *Dideopsis aegrota* (Fabricius, 1805) | Syrphidae | Diptera | Pramanik et al., 2023 |
| 51 | *Episyrphus balteatus* (De Geer, 1776) | Syrphidae | Diptera | Pramanik et al., 2023 |
| 52 | *Ischiodon scutellaris* (Fabricius, 1805) | Syrphidae | Diptera | Pramanik et al., 2023 |
| 53 | *Eristalinus megacephalus* (Rossi, 1794) | Syrphidae | Diptera | Pramanik et al., 2023 |
| 54 | *Mesembrius bengalensis* (Wiedemann, 1819) | Syrphidae | Diptera | Pramanik et al., 2023 |
| 55 | *Syrphus* sp. | Syrphidae | Diptera | Thapa, 2006 |
| 56 | *Bactrocera cucurbitae* (Coquillett, 1899) | Tephritidae | Diptera | Rima, 2017 |
| 57 | *Platensina acrostacta* (Wiedemann, 1824) | Tephritidae | Diptera | Pramanik et al., 2023 |
| 58 | *Hermetia* sp. | Stratiomyidae | Diptera | Srikanth et al., 2013 |
| 59 | *Sargus metallinus*Fabricius, 1805 | Stratiomyidae | Diptera | Pramanik et al., 2023 |
| 60 | *Musca domestica* Linnaeus, 1758 | Muscidae | Diptera | Pramanik et al., 2023 |
| 61 | *Atherigona orientalis* Schiner, 1868 | Muscidae | Diptera | Pramanik et al., 2023 |
| 62 | *Lucilia porphyrina* (Walker, 1856) | Calliphoridae | Diptera | Pramanik et al., 2023 |
| 63 | *Lucilia cuprina* (Wiedemann, 1830) | Calliphoridae | Diptera | Pramanik et al., 2023 |
| 64 | *Mimegralla albimana* (Doleschall, 1856) | Micropezidae | Diptera | Pramanik et al., 2023 |
| 65 | *Homoneura bengalensis* (Macquart,1843) | Lauxaniidae | Diptera | Pramanik et al., 2023 |
| 66 | *Mimegralla albimana* (Doleschall, 1856) | Micropezidae | Diptera | Pramanik et al., 2023 |
| 67 | *Aulacophora semipalliata* Fairmaire, 1891 | Chrysomelidae | Coleoptera | Morimoto et al., 2004 |
| 68 | *Aulacophora intermedia* Jacoby, 1892 | Chrysomelidae | Coleoptera | Prajapati et al., 2021 |
| 69 | *Aulacophora foveicollis* (Lucas, 1849) | Chrysomelidae | Coleoptera | Srikanth et al., 2013 |
| 70 | *Diabrotica undecimpunctata* Mannerheim, 1843 | Chrysomelidae | Coleoptera | Rima, 2017 |
| 71 | *Coccinella septempunctata* Linnaeus, 1758 | Coccinellidae | Coleoptera | Rima, 2017 |
| 72 | *Cheilomenes sexmaculata* (Fabricius, 1781) | Coccinellidae | Coleoptera | Prajapati et al., 2021 |
| 73 | *Illeis cincta* (Fabricius, 1798) | Coccinellidae | Coleoptera | Prajapati et al., 2021 |
| 74 | *Coccinella transversalis* Fabricus, 1781 | Coccinellidae | Coleoptera | Prajapati et al., 2021 |
| 75 | *Coryna* sp. | Meloidae | Coleoptera | Morimoto et al., 2004 |
| 76 | *Epuraea (Haptoncus) motschulskyi* (Reitter) | Nitidulidae | Coleoptera | Dasgupta et al., 2018 |
| 77 | *Cyclocephala paraguayensis*Arrow, 1903 | Melolonthidae | Coleoptera | Favaris et al., 2020 |
| 78 | *Nezara viridula* (Linnaeus, 1758) | Pentatomidae | Hemiptera | Prajapati et al., 2021 |
| 79 | *Dysdercus cingulatus* (Fabricius, 1775) | Pyrrhocoridae | Hemiptera | Prajapati et al., 2021 |
| 80 | *Nesidiocoris tenuis* (Reuter, 1895) | Miridae | Hemiptera | Shrivastava, 1990 |
| 81 | *Therioaphis trifolii*(Monell, 1882) | Aphididae | Hemiptera | Rima, 2017 |
| 82 | *Phaneroptera falcata* (Poda, 1761) | Tettigoniidae | Orthoptera | Padhiyar and Patel, 2021 |
| 83 | *Hieroglyphus banian* (Fabricius, 1798) | Acrididae | Orthoptera | Subhakar and Sridevi, 2015 |
| 84 | *Diplacodes trivialis* (Rambur, 1842) | Libellulidae | Odonata | Padhiyar and Patel, 2021 |
| 85 | *Megalurothrips usitatus* (Bagnall, 1913) | Thripidae | Thysanoptera | Rima, 2017 |
| 86 | *Mantis religiosa*(Linnaeus, 1758) | Mantidae | Mantodea | Subhakar and Sridevi, 2015 |

**4. Pollination biology**

In the process of evolution, every living organism constantly modifies its genome to counter the resistance imposed by biotic and abiotic factors (Shapiro, 2017). During this process, the developed characters are preserved in their genetic material and passed on to their progenies through parental chromosomal exchange during reproduction (Kuckuck et al., 2020). Hence, reproduction plays a vital role in the continuation and evolution of species (Anholt et al., 2020). Despite this significance, many living organisms meet their reproductive needs through the voluntary union of two opposite sexes. However, plants, due to their immobility, need extra agents to fulfill their reproductive needs, which can be achieved through pollination. In cross-pollination, wind, water, and animal agents transfer the pollen grains of staminate flowers to the receptive stigmas of pistillate flowers (Saha et al., 2023). However, among the pollination vectors, one-third of human dietary requirements, 87.5% of wildflower pollination (approximately 308,000 plant species), 85% of human consumption and global economy trades, and 35% of global crop production are fulfilled through animals (Rhodes, 2018).

Among animals, insects are the major pollination vectors with 141,604 species of Lepidopterans,77,300 species of Coleopterans, 70,117 species of Hymenopterans, 54,417 species of Dipterans, 1,466 species of Thysanopterans, 1,193 species of Orthopterans, 1,036 species of Hemipterans, 407 species of Collembolans, 366 species of Blattodeans, 293 species of Neuropterans, 144 species of Trichopterans, 76 species of Mecopterans, 57 species of Psocopterans, 37 species of Plecopterans, and 20 species of Dermapteran insects visiting the flowers (Wardhaugh, 2015). Despite this large number of floral visitors, only a few insects act as efficient pollinators, whereas many insect species eat pollen and nectar without contributing to pollination (Nepi et al., 2018; Bergamo and Sazima, 2018). Indeed, apart from the flower color and flower volatiles (Murray et al., 2024) several other factors govern the insect visitor to act as an efficient pollinator such as the length and width of petals which the insect visitor uses as a platform to operate (Reghunath et al., 2024), the distance between the floral surface to floral rewards (pollen and nectar) which is convenient for the insect visitor to access floral rewards freely with their mouthparts (Carneiro et al., 2024), the chemical composition of nectar and pollen which is essential to meet the nutritional requirements of the insect floral visitor (Yokota et al., 2024), the correlation between the floral anthesis and time of activity of insect visitors and maximum stigmatic receptivity of the flower, the time spent by the insect visitor for collection of floral rewards (foraging speed), number of flowers visited per unit time (foraging rate), number of pollen grains deposited per visit on the stigma of pistillate flower, and the pollination efficiency index of insect floral visitors (Sagili et al., 2024; Nayak et al., 2022) where insect species are how quickly and efficiently visit the flowers and transfer the pollen grains. Hence, if the following parameters are convenient for the insect visitor, then it acts as an efficient pollinator. If not, it simply prefers to forage on other flowers. Thus, considering the significance of the pollination ecological factors in achieving pollination saturation, a comprehensive review is undertaken on the abundance, foraging speed, and foraging rate of bottle-gourd insect floral visitors.

**4.1 Abundance**

Studies on the per cent relative abundance of insect floral visitors of bottle gourd (Subhakar and Sridevi, 2015; Manju et al., 2022; Prajapati et al., 2021; Padhiyar and Patel, 2021) revealed that *Epuraea motschulskyi* is the dominant visitor to bottle gourd flowers with 72.04% relative abundance of species followed by *Nesidiocoris tenuis* with37.65%, *Aulacophora foveicollis* with 26.96%, *Diaphania indica* with 19.92%, *Hippotion celerio* with 18.03%, *Arthroschista hilaralis* with 17.27%, *Bactrocera cucurbitae* with 12.05%, *Anadevidia peponis* with 10.63%, *Hieroglyphus banian* with 8.60%, *Oecophylla smaragdina* with 7.33%, *Cheilomenes sexmaculata* with 7.26%, *Mantis religiosa*with 6.40%, *Apis dorsata* with 5.82%, *Agrius convolvuli* with 4.71, *Camponotus compressus* with 4.41%, *Nezara viridula* with 3.69%, *Coccinella transversalis* with 3.39%, *Phaneroptera falcata* with 2.35%, *Pieris brassicae* with 2.27%, *Apis cerana* with 2.03%, *Delias eucharis* with 1.95%, *Pachliopta hector* with 1.65%, *Aulacophora intermedia* with 1.19%, *Diplacodes trivialis* with 1.18%, *Danaus chrysippus*with 0.72%, *Dysdercus cingulatus* with 0.69%, *Spoladea recurvalis* with 0.56%, *Xylocopa* sp. with 0.47%, *Megachile (Eutricharaea)* sp. with 0.44%, *Eurema hecabe* with 0.44%, *Illeis cincta* with 0.31%, and *Halictus* sp. with 0.20% (Table 2).

Furthermore, a study by Rima (2017) on the abundance of insect floral visitors of bottle gourd by adopting parameters such as the number of insect species visiting bottle gourd flowers in one square meter area in 10 minutes revealed that on bottle gourd flowers in one square meter area, the mean number of *Formica* sp. is more with 9.46 species/m2/10 minutes followed by *Therioaphis trifolii* with 1.91, *Apis mellifera* with 1.86, *Apis dorsata* with 1.67, *Halictus* sp. with 1.15, and *Bactrocera cucurbitae* with 1.10 (Table 2).

Additionally, Manju et al. (2022) conducted a similar study by changing parameters such as the number of insect species visiting bottle gourd flowers in one meter square area in 5 minutes reported that on bottle gourd flowers, *Epuraea motschulskyi* is more in number with 15.88 beetles/m2/5 minutes followed by *Nesidiocoris tenuis* with 4.98, *Apis cerana* with 0.45, *Pachliopta hector* with 0.36, *Aulacophora foveicollis* 0.18, *Hippotion celerio* with 0.10, *Diaphania indica* with 0.04, and *Halictus* sp. with 0.04 (Table 2).

In the following studies, the dominant visitors of bottle gourd flowers such as *Epuraea motschulskyi*, *Nesidiocoris tenuis*, and *Aulacophora foveicollis* were classified as pests (Mondal et al., 2022; Raghavendra et al., 2022), where *Epuraea motschulskyi* caused pollen limitation, and *Nesidiocoris tenuis* and *Aulacophora foveicollis* caused fruit damage. In contrast, *Epuraea motschulskyi* is a potential pollinator of the pointed gourd (*Trichosanthes dioica*) (Halder et al., 2024). Despite the significance of *Epuraea motschulskyi* in cucurbitaceous pointed gourd pollination, the same study needs to be conducted on bottle gourd and from the obtained results, by considering the cost of pollination and pollen damage, the final decision regarding pest or pollinator will be classified through cost-benefit ratio. Furthermore, bottle gourd flowers are mostly open at night, when many lepidopteran insects like moths and hawk moths visit the flowers. Hence, by considering the correlation between the nocturnal blooming of bottle gourd and nocturnal lepidopteran visits to bottle gourd flowers, future studies will be needed to be conducted on the contributions of nocturnal pollination, especially lepidopterans in bottle gourd production.

**Table 2. Abundance of insect floral visitors of the bottle gourd**

|  |  |  |
| --- | --- | --- |
| **Species** | **%Relative abundance of species** | **Reference** |
| *Epuraea (Haptoncus) motschulskyi* (Reitter) | 72.04  31.76  12.24 | Manju et al., 2022  Padhiyar and Patel, 2021  Prajapati et al., 2021 |
| *Nesidiocoris tenuis* (Reuter, 1895) | 37.65  22.61  17.00 | Padhiyar and Patel, 2021  Manju et al., 2022  Prajapati et al., 2021 |
| *Aulacophora foveicollis* (Lucas, 1849) | 26.9  9.41  7.60  0.83 | Prajapati et al., 2021  Padhiyar and Patel, 2021  Subhakar and Sridevi, 2015  Manju et al., 2022 |
| *Diaphania indica* (Saunders, 1851) | 19.92  4.71  0.63  0.17 | Subhakar and Sridevi, 2015  Padhiyar and Patel, 2021  Prajapati et al., 2021  Manju et al., 2022 |
| *Hippotion celerio* (Linnaeus, 1758) | 18.03  4.71  0.47 | Subhakar and Sridevi, 2015  Padhiyar and Patel, 2021  Manju et al., 2022 |
| *Arthroschista hilaralis* (Walker, 1859) | 17.27 | Subhakar and Sridevi, 2015 |
| *Bactrocera cucurbitae* (Coquillett, 1899) | 12.05 | Prajapati et al., 2021 |
| *Anadevidia peponis* (Fabricius, 1775) | 10.63  3.52 | Subhakar and Sridevi, 2015  Padhiyar and Patel, 2021 |
| *Hieroglyphus banian* (Fabricius, 1798) | 8.60 | Subhakar and Sridevi, 2015 |
| *Oecophylla smaragdina* (Fabricius, 1775) | 7.33 | Subhakar and Sridevi, 2015 |
| *Cheilomenes sexmaculata* (Fabricius, 1781) | 7.26 | Prajapati et al., 2021 |
| *Mantis religiosa*(Linnaeus, 1758) | 6.40 | Subhakar and Sridevi, 2015 |
| *Apis dorsata* Fabricius, 1793 | 5.82 | Prajapati et al., 2021 |
| *Agrius convolvuli* (Linnaeus, 1758) | 4.71 | Padhiyar and Patel, 2021 |
| *Camponotus compressus* (Fabricius, 1787) | 4.41 | Prajapati et al., 2021 |
| *Nezara viridula* (Linnaeus, 1758) | 3.69 | Prajapati et al., 2021 |
| *Coccinella transversalis* Fabricus, 1781 | 3.39 | Prajapati et al., 2021 |
| *Phaneroptera falcata* (Poda, 1761) | 2.35 | Padhiyar and Patel, 2021 |
| *Pieris brassicae* (Linnaeus, 1758) | 2.27 | Subhakar and Sridevi, 2015 |
| *Apis cerana* Fabricius, 1793 | 2.03  1.82 | Manju et al., 2022  Prajapati et al., 2021 |
| *Delias eucharis* (Drury, 1773) | 1.95 | Subhakar and Sridevi, 2015 |
| *Pachliopta hector* (Linnaeus, 1758) | 1.65 | Manju et al., 2022 |
| *Aulacophora intermedia* Jacoby, 1892 | 1.19 | Prajapati et al., 2021 |
| *Diplacodes trivialis* (Rambur, 1842) | 1.18 | Padhiyar and Patel, 2021 |
| *Danaus chrysippus*(Linnaeus, 1758) | 0.72 | Prajapati et al., 2021 |
| *Dysdercus cingulatus* (Fabricius, 1775) | 0.69 | Prajapati et al., 2021 |
| *Spoladea recurvalis* (Fabricius, 1775) | 0.56 | Prajapati et al., 2021 |
| *Xylocopa* sp. | 0.47 | Prajapati et al., 2021 |
| *Megachile (Eutricharaea)* sp. | 0.44 | Prajapati et al., 2021 |
| *Eurema hecabe* (Linnaeus, 1758) | 0.44 | Prajapati et al., 2021 |
| *Illeis cincta* (Fabricius, 1798) | 0.31 | Prajapati et al., 2021 |
| *Halictus* sp. | 0.20 | Manju et al., 2022 |
|  | **Abundance (no./m2/10 minutes)** |  |
| *Formica* sp. | 9.46 | Rima, 2017 |
| *Therioaphis trifolii*(Monell, 1882) | 1.91 | Rima, 2017 |
| *Apis mellifera* Linnaeus, 1758 | 1.86 | Rima, 2017 |
| *Apis dorsata* Fabricius, 1793 | 1.67 | Rima, 2017 |
| *Halictus* sp. | 1.15 | Rima, 2017 |
| *Bactrocera cucurbitae* (Coquillett, 1899) | 1.10 | Rima, 2017 |
|  | **Abundance (no./m2/5 minutes)** |  |
| *Epuraea (Haptoncus) motschulskyi* (Reitter) | 15.88 | Manju et al., 2022 |
| *Nesidiocoris tenuis* (Reuter, 1895) | 4.98 | Manju et al., 2022 |
| *Apis cerana* Fabricius, 1793 | 0.45 | Manju et al., 2022 |
| *Pachliopta hector* (Linnaeus, 1758) | 0.36 | Manju et al., 2022 |
| *Aulacophora foveicollis* (Lucas, 1849) | 0.18 | Manju et al., 2022 |
| *Hippotion celerio* (Linnaeus, 1758) | 0.10 | Manju et al., 2022 |
| *Diaphania indica* (Saunders, 1851) | 0.04 | Manju et al., 2022 |
| *Halictus* sp. | 0.04 | Manju et al., 2022 |

**4.2 Foraging speed and foraging rate**

Studies on the foraging speed of insect floral visitors of bottle gourd (Morimoto et al., 2004) revealed that *Apis mellifera* has the highest foraging speed of 48.00 s followed by *Ceratina* sp. (36.00), *Coryna* sp. (33.50), *Gorgyra johnstoni* (32.60), *Anthophora* sp. (5.50), *Agrius convolvuli* (1.50), *Belenois creona* (1.00), and *Anthene lunulate* (1.00). Subsequently, studies on the foraging rate (Morimoto et al., 2004) reported that *Hippotion celerio* has the highest foraging rate of 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 3).

In foraging behavioral studies, apart from foraging speed and foraging rate, additional parameters such as time of initiation of foraging, peak period of foraging and, termination of foraging parameters need to be studied for domesticated bees like *Apis mellifera*, *Apis cerana*, *Apis florea* and *Tetragonula iridipennis*. By doing so, the capacity of worker bees concerning the number of flowers pollinated by bees in one day during their foraging period will be known and combining this knowledge with the number of pistillate flowers produced per vine and acre, which helps in understanding the requirement of bee boxes in apiary and controlled pollination studies. Additionally, the following information also helps in the allocation of pesticidal sprays during the blooming period. Furthermore, in the case of *Apis dorsata*, after the termination of foraging, while returning to hives, tracking will help with bee hives finding.

**Table 3. 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** |
| *Apis mellifera* Linnaeus, 1758 | 48.00 | 2.00 | Morimoto et al., 2004 |
| *Gorgyra johnstoni* (Butler, 1894) | 32.60 | 5.00 | Morimoto et al., 2004 |
| *Agrius convolvuli* (Linnaeus, 1758) | 1.50 | 1.00 | Morimoto et al., 2004 |
| *Hippotion celerio* (Linnaeus, 1758) | 3.20 | 6.50 | Morimoto et al., 2004 |
| *Belenois creona* (Cramer, 1776) | 1.00 | 2.00 | Morimoto et al., 2004 |
| *Ceratina* sp. | 36.00 | 1.00 | Morimoto et al., 2004 |
| *Anthene lunulate* (Trimen, 1894) | 1.00 | 1.00 | Morimoto et al., 2004 |
| *Coryna* sp. | 33.50 | 2.00 | Morimoto et al., 2004 |
| *Anthophora* sp. | 5.50 | 2.00 | Morimoto et al., 2004 |

**5. Controlled pollination treatments**

**5.1 Pollination exclusion**

In pollination exclusion studies (Padhiyar and Patel, 2022; Srikanth et al., 2013), the tagged flowers of bottle-gourd plants were subjected to no pollination by covering the pistillate flowers before anthesis with paper bags where the pollinators could not enter. As a result, in all pollination exclusion studies (Padhiyar and Patel, 2022; Srikanth et al., 2013), the percent fruit set was zero and the yielded results strongly supported the existing statement that the bottle gourd is predominantly a cross-pollinated plant (Table 4).

**5.2 Hand pollination**

In hand pollination studies of the bottle gourd (Rima, 2017), the pistillate flower buds are randomly tagged and covered with paper bags. Later, at the time of maximum stigmatic receptivity, tagged flowers were subjected to hand pollination followed by closure with paper bags. Furthermore, after a successful fruit set, the parameters such as per cent fruit set, fruit length, and weight were calculated from the tagged flowers. As a result, previous studies (Rima, 2017) recorded 71.52% fruit set, 89.70 cm fruit length, and 2200.54 gm fruit weight in the hand pollination of bottle gourd (Table 4).

In hand pollination, farmers pay extra wages to hire labor during the blooming period to collect pollen grains from staminate flowers and dust them on pistillate flowers. Indeed, hand pollination gives superior results, but profit is based on the market price. If the per-unit market price of the commodity compensates for the additional cost of labor wages in hand pollination, then hand pollination benefit farmers. If this is not the case, hand pollination costs time and manpower. Additionally, in some instances, bottle gourd flowers were opened at night and it was difficult for a farmer to perform hand pollination at night. Furthermore, in the case of hand pollination, farmers need to cut the staminate flowers, where the wounds act as an entrance for pathogens.

**5.3 Open pollination with attractants**

In open pollination studies with bee attractants, the fruit set percentage, length, and weight were calculated from the bottle gourd plots by spraying with bee attractants (citral-a and citral-b) during flowering. As a result, Srikanth et al. (2013) recorded, 69.10% fruit set, 47.29 cm fruit length, and 2130.00 gm fruit weight in the presence of citral-a and 67.40% fruit set, 47.30 cm fruit length, and 2060.00 gm fruit weight in the presence of citral-b (Table 4).

In behavioral studies, in addition to bee attractants, similar studies need to be conducted on the impact of ecological engineering approaches on pollination, such as chocolate-box ecology and floral stripping, where diverse flowering plants are cultivated alongside crops and on bunds. As a result, ecologically engineered fields may attract more pollinators because of their diversified flower collection. Further research is needed to examine the effects of artificially produced floral volatiles (Dötterl and Gershenzon, 2023) on pollinator diversity, abundance, and fruit set percentage. If the outcomes are significant, using floral volatiles as sprays with appropriate formulas would be advisable.

**5.4 Open pollination**

In open pollination studies (Srikanth et al., 2013; Padhiyar and Patel, 2022; Rima, 2017), the bottle gourd flowers are tagged and left as such for open pollination. Later, from the tagged flowers, the percent fruit set, fruit length, and weight were calculated. Srikanth et al., 2013 recorded 63.48% fruit set, 43.93 cm fruit length and 961.24 gm of fruit weight, Padhiyar and Patel, 2022 recorded 59.67% fruit set and 1870.00 gm of fruit weight, and Rima, 2017 recorded 60.85% fruit set, 80.90 cm fruit length and, 1700.56 gm fruit weight in open pollination (Table 4).

**5.5 Controlled *Apis cerana indica* pollination**

In controlled *Apis cerana indica* pollination, the bottle gourd crop was subjected only to *Apis cerana indica* pollination by placing bee boxes inside the crop and covering the crop with a mosquito net during flowering. Hence, in the following study, Padhiyar and Patel, 2022 recorded 54.03% fruit set and 878.57 gm fruit weight by placing 4 *Apis cerana indica* boxes at 10% flowering of bottle gourd (Table 4).

In controlled pollination studies, in addition to *Apis cerana indica* pollination studies, similar studies will need to be conducted on an economically significant Italian bee known as *Apis mellifera*. Likewise, if the obtained results, such as *Apis mellifera* aid in bottle gourd pollination, then it will be good to recommend keeping *Apis mellifera* boxes with bottle gourd crop that will provide additional income to farmers.

**5.6 Honey bee pollination exclusion**

In honey bee pollination exclusion studies (Rima, 2017), the selected bottle gourd planted plots were subjected to no bee pollination by covering 40 mesh nylon nets where bees did not enter the plots. As a result, Rima, (2017) recorded a 45.65% fruit set, 62.70 cm fruit length, and 1500.40 gm fruit weight in a honey bee pollination exclusion study (Table 4). Additionally, the following methodology will be extended to study the individual contribution of dominant floral visitors on the yield parameters of the bottle gourd.

**Table 4. Controlled pollination treatments in the bottle gourd**

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

**6. Conclusion**

Studies on insect pollination of bottle gourd revealed that during the blooming period of bottle gourd, 86 insect species visited bottle gourd flowers, with *Epuraea motschulskyi* being the most abundant and *Apis mellifera* and *Hippotion celerio* having the highest foraging speed and foraging rate. Moreover, in the controlled pollination studies, hand pollination achieved superior results. Hence, it is clear from the following studies that many insect species are willing to provide pollination services to the bottle gourd, but lower yields are obtained compared to hand pollination. Hence, future studies will concentrate on the factors that lead to insufficient pollination and the contribution of dominant visitors such as *Epuraea motschulskyi* in bottle gourd production.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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