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Flower-insect interactions with special reference to honey bees with some plant species (*Albizia lebbek*, *Calliandra brevipes*, *Calliandra haematocephala*, *Mimosa pudica*, *Pithecellobium dulce*, *Hamelia patens*, *Mitragyna parvifolia* and *Hugonia mystax*)

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ABSTRACT

Albizia lebbek, *Calliandra brevipes*, *Calliandra haematocephala*, *Mimosa pudica*, *Pithecellobium dulce*, *Hamelia patens*, *Mitragyna parvifolia* and *Hugonia mystax* are included in this study to evaluate their importance for insects as food and also the role of insects in the pollination of these species. *Calliandra* species, *M. pudica* and *P. dulce* are andromonoecious while the remaining species are hermaphroditic. The reproductive unit of attraction is the raceme/head/polychasial cyme with numerous to several flowers in all these species except *H. patens* and *H. mystax* in which individual flower is the unit of attraction to flower visitors. The pollen grains are either tetrads or polyads in *A. lebbek*, *Calliandra* species, *M. pudica* and *P. dulce*. These units of pollen grains are advantageous for pollen collecting bees since each unit consists of 4 or 16 grains. Additionally, the clustered state of flowers in the raceme facilitate such bees to collect as many pollen units as possible from several closely arranged flowers in a single visit without spending additional energy expenditure for flight and search the flowers for forage collection. In *H. patens*, *M. parvifolia* and *H. mystax*, the flowers produce monad pollen grains but each flower produces copious pollen. All plant species are nectariferous but nectar is secreted in measurable quantity in the flowers of *H. patens* and *H. mystax* while it is secreted in traces in the flowers of all other plant species. All these species are pollinated by honey bees. *H. mystax* is pollinated also by digger bees and small carpenter bees. Further, *A. lebbek*, *P. dulce*, *H. patens*, *M. parvifolia* and *H. mystax* are pollinated by 1 to 3 butterfly species. A beetle, *Mylabris phalerata* utilizes the flowers of *A. lebbek* as food by eating the floral parts; its feeding activity is found to be negatively affecting the reproductive

capacity of this tree species. Therefore, all these plant species are very important as pollen and/or nectar source for honey bees while some plant species provide nectar to butterflies that visit them which in return effect pollination. In Oman, *A. lebbeck*, *P. dulce* and *Mimosa* sp. occur in certain habitats and these species have been reported to be the sources of pollen and nectar for honey bees.

Keywords: *Albizia lebbeck*, *Calliandra brevipes*, *Calliandra haematocephala*, *Mimosa pudica*, *Pithecellobium dulce*, *Hamelia patens*, *Mitragyna parvifolia*, *Hugonia mystax*, honey bees, butterflies, pollen, nectar, pollination.

1. INTRODUCTION

The genus *Albizia* has about 120 to 140 species of small to large trees with high species diversity in tropical America, then tropical Africa, Southeast Asia, and Malaysia (Lewis and Arce 2005). *A. julibrissin* is an out-crossing insect pollinated species (Irwin et al. 2003). *A. lebbeck* is native to Indomalaya, New Guinea and Northern Australia but it is widely naturalized and also cultivated in both tropical and subtropical regions (Ali 1973; Brown 1997). But, other reports state that it is native to tropical Africa, Asia and Northern Australia and widely naturalized in sub-humid and semi-arid tropical and subtropical regions where there is a marked dry season and a reliable rainy season (Lowry et al. 1992; Duke 1983; Cook et al. 2005). *A. lebbeck* is apparently principally pollinated by wind. But, the flowers being very attractive and fragrant attract bees which likely have a pollination role (Parrotta 1988; Lowry et al. 1994). But, Latif et al. (2019) reported that *A. lebbeck* is pollinated by bees, flies and butterflies, but, of these, certain bees such as *Apis dorsata*, *Nomia oxybeloides* and *Amegilla cingulata* are effective pollinators.

Calliandra is chiefly of Neotropical with approximately 130 species of shrubs and trees (Barneby 1998). In this genus, the flowers are borne in paniculate racemes and produce numerous stamens with filaments fused at the base, forming a tubular structure which is concealed by corolla while the distal portion is exposed far above the corolla (MacQueen and Hernandez 1997). The anthers display a unique mode of pollen presentation; they produce a sticky substance which attaches the polyad to the anther. The polyads possess 8 undivided pollen grains of which two grains placed in the center are surrounded by all other 6 grains (Santos and Romao 2008). A few species have been studied for their reproductive ecology. Arroyo (1981) reported that *C. schultzei* is pollinated by hummingbirds. Chamberlain and Rajaselvam (1996) reported that *C. calothyrsus* is andromonoecious and pollinated by nectarivorous bats and hawkmoths. Rathcke and Kass (2003) reported that *C. haematomma* var. *correllii* is andromonoecious and pollinated by the hummingbird, Bahamas Woodstars. Butterflies and wasps also occasionally visit the flowers but they mainly act as nectar thieves. Hernandez-Conrique et al. (2007) reported that *C. longipedicellata* is pollinated by hawkmoths, bats hummingbirds and diurnal insects.

The genus *Mimosa* has about 420 species of herbs, shrubs and ornamental trees distributed throughout the tropics and subtropics of South America, North America, Africa, Asia and Australia (Rizwan et al. 2022). Of these, *M. pudica* and *M. tenuiflora* are well noted. *M. pudica* is native to the tropical Americas but it is now naturalized in all tropical regions of the world. In this species, the leaves fold inwards and droop, when touched or exposed to heat, and return back to their normal state after a few minutes; it is widely cultivated in many areas for its curiosity value as a house plant in temperate regions and outdoor plant in the tropical regions. *M. tenuiflora* is used as a psychoactive brew used socially and as ceremonial spiritual medicine by indigenous peoples of the Amazon basin in South America (Gledhill 2008; Austin 2004). In *M. lewisii*, the anthesis is nocturnal in occurrence and functional only in the same night. When the flower heads expand, they produce large drops of nectar which are freely exposed and held in the spaces between filaments. The flowers are hermaphroditic with stiff staminal filaments and style, and pollinated by the glossophagine bat, *Lonchophylla mordax* which laps the nectar while in hovering posture. During daytime, hummingbirds exploit the worn capitula without any role in pollination (Vogel et al. 2005). *M. diplotricha* is pollinated by bees in Nigeria (Egbon et al. 2019). In southeastern Brazil, *M. bimucronata* displays a generalist entomophilous syndrome and is pollinated by hymenopterans, dipterans and coleopterans (Silva et al. 2011). Sierra et al. (2009) reported that *M. pigra* pollen was the highest in the pollen loads of wild bees in the Dam Project area in Colombia. *M. pudica* is used as pollen source by solitary bees (Percival 1974) and its pollen is the most common in the pollen baskets of *Exomalopsis globosa* and *E. similis* in Jamaica (Raw 1976). *Trigona collina* collects the pollen of *M. pudica* in a lowland mixed-dipterocarp forest in Malaysia (Eltz 2001). In Thailand, *M. pudica* has been reported to be the main pollen source for *A. dorsata*, *A. cerana* and *A. florea* (Suwannapong et al. 2013). In Cameroon, *M. pudica* is visited and pollinated by flies and bees, and in case of bees, *Apis mellifera* and *Xylocopa torrida* paid more visits than all other bees. Further, *A. mellifera* pollination efficiency when tested showed that fruit set and seed set rate increase substantially indicating that it is very efficient pollinator (Taimanga and Fernand-Nestor 2018).

The genus *Pithecellobium* is a large group of tropical and subtropical shrubs and trees distributed in the Old and New worlds. *P. dulce* is native to the Pacific Coast and nearby highlands of Mexico, Central America and northern South America but it has been introduced into many tropical countries including India (Trimen 1894; Khanzada et al. 2013). It is now a widespread tree species in all tropical regions of the world due to its planting and naturalization (Sunarjono et al. 1991). It is pollinated by large and small bees (Brewbaker 1992).

The genus *Hamelia* comprises 28 species distributed in Americas from Florida and Mexico to Paraguay (Britton 1912). *Hamelia patens* is self-incompatible (Louis et al. 2012), pollinated by hummingbirds (Collwell 1995; Lasso and Naranjo 2003), and also by butterflies, bees and wasps indicating that this species has a generalist pollination syndrome (Peters 2014). Further, certain birds rob nectar from the flowers of *H. patens* (Lasso and Naranjo 2003).

The genus *Mitragyna* is paleotropical and comprises of 10 species of shrubs or trees of which six species, *M. speciosa*, *M. tubulosa*, *M. parvifolia*, *M. hirsuta*, *M. diversifolia* and *M. rotundifolia* are distributed widely in different regions in Asia including Malaysia, Indonesia, Thailand, Vietnam, the Philippines, New Guinea, Bangladesh and India, while the other four species, *M. ciliata*, *M. inermis*, *M. stipulosa* and *M. africanus* are widely distributed in Africa (Beckett et al. 1963; Puff et al. 2005; Fang et al. 2012; Lofstrand et al. 2014). The species in this genus are characterized by a dense inflorescence with flowers arranged in compact round heads, fused flowers and ovaries. The ovaries are 2-celled with a cylindrical stigma (Razafimandimbison and Bremer 2002). *Mitragyna* species grow well in wet or moist soils or even water-logged areas. They flourish well during wet season and shed leaves during dry season (Hassan et al. 2013). *Mitragyna* pollen is very partially airborne as it accounted for only about 1% of total airspora (Chauhan and Goyal 2006). *M. rotundifolia* is mainly pollinated by bees and butterflies (Kato et al. 2008).

Genus *Hugonia* is a paleotropical climbing shrubby taxon with 40 species distributed in Africa, Mauritius and Asia but in India, only 2 species, *H. ferruginea* and *H. mystax* occur (Anonymous 1959). *H. ferruginea* is confined to Northeastern India while *H. mystax* has wide distribution in dry scrub forests, sub-tropical and tropical deciduous and evergreen forests of eastern and western peninsular India and Sri Lanka (Gavade 2009; Raju et al. 1997). *H. serrata* is a woody liana endemic to the Mascarene Islands of La Reunion and Mauritius in the Southern Indian Ocean. The flowers are tristylous with bimorphic pollen, self-incompatible and pollinated by insects (Meeus et al. 2011). *H. mystax* is distylous, self-incompatible and pollinated by *Apis* bees (Raju et al. 1997).

The work reviewed here indicate that there is little work done on the genera *Albizia*, *Calliandra*, *Mimosa*, *Pithecellobium*, *Hamelia*, *Mitragyna* and *Hugonia* when compared to the species listed under them with reference to insect-flower interactions and pollination. With this backdrop, the present study is contemplated to report on insect-flower interactions with special reference to honeybees and their role in the pollination of *Albizia lebbek* (L.) Benth., *Calliandra brevipes* Benth, *Calliandra haematocephala* Hassk, *Mimosa pudica* L., *Pithecellobium dulce* (Roxb.) Benth. (Fabaceae: Caesalpinoideae), *Hamelia patens* Jacq., *Mitragyna parvifolia* (Roxb.) Korth. (Rubiaceae) and *Hugonia mystax* L. (Linaceae).

2. MATERIALS AND METHODS

Albizia lebbek, *Calliandra brevipes*, *Calliandra haematocephala*, *Mimosa pudica*, *Pithecellobium dulce*, *Hamelia patens*, *Mitragyna parvifolia* and *Hugonia mystax* occurring in within the scrub-jungle habitats of Visakhapatnam city, Andhra Pradesh, India, were used for the study during June 2021-February 2022. Floral features, nectar production and pollen unit were examined during the flowering season of these plant species. Twenty five mature buds for each plant species were tagged to record the flower-opening time schedule. Field observations were made during the flowering season of all these species with reference flower-visiting insects, their foraging time and forage sought. The details of flower-insect interactions, pollination role played by insects and the importance of plants as pollen and/or nectar were recorded systematically and interpreted with the published works. In Oman, arid habitats are most common and represented mostly by sand dunes, rock and gravel desert and followed by semi-deciduous cloud forests and evergreen juniper-woodlands characterized by high species diversity with many endemic species (Patzelt 2014, 2015). *A. lebbek*, *P. dulce* and *Mimosa* sp. are reported in certain habitats of Oman. Of these, the first two species are naturalized and appear to be important in tree cover (Patzelt et al. 2022) while there is no clear information about the occurrence of all other species included in this study. It is reported that all the three species stated above have been reported to be the sources of pollen and nectar for honey bees (Sajwani et al. 2014).

3. OBSERVATIONS

***Albizia lebbek*:** It is a perennial deciduous dry season blooming tree species with pinnate leaves. The flowering occurs during February-May (Figure 1a). The flowers are borne in rounded axillary pedunculate corymbose racemes. They are pedicellate, large, greenish-yellow, hermaphroditic, sweet smelling and emit more fragrance in the evening time by which time the leaves fold

together. The calyx is tubular at base and 5-lobed towards the apex. The corolla has narrow tube with 5 inconspicuous greenish lanceolate petals. The stamens are numerous, free, very long and well exposed with small ditheous anthers; the filaments are connate at base forming a short tube. The ovary is subsessile with filiform style and minute stigma placed almost at the level of stamens (Figure 1e,f). The flowers are open all night and until early morning while the anthers dehisce by longitudinal lists after 2 hours from the time of flower-opening (Figure 1b-d). Individual anthers produce several 16-grained polyads. The nectar is secreted in traces and is well exposed to sunlight. The flowers were visited by honey bees, *Apis dorsata*, *A. cerana*, *A. florea* and *Trigona iridipennis* consistently throughout the day. They utilized both pollen and nectar as food source. Since nectar is in traces, they mainly concentrated on pollen collection; pollen collected by them was visible as pollen basket on the outside of their hind tibia. The bees spent more time at each flower collecting pollen due to the presence of many stamens and hence they were able to effect mostly self-pollination by autogamy and geitonomy. Butterflies such as *Papilio polytes* (Figure 1g,h), *Catopsilia pyranthe* (Figure 1i) and *Catopsilia pomona* (Figure 1j) also visited regularly for nectar collection. They moved quickly from flower to flower in search of more nectar from the same and different conspecific individuals due to the presence of traces of nectar. A blister beetle, *Mylabris phalerata* (Figure 1k) was found eating the stamens, style and stigma affecting the fruit and seed set rate negatively.

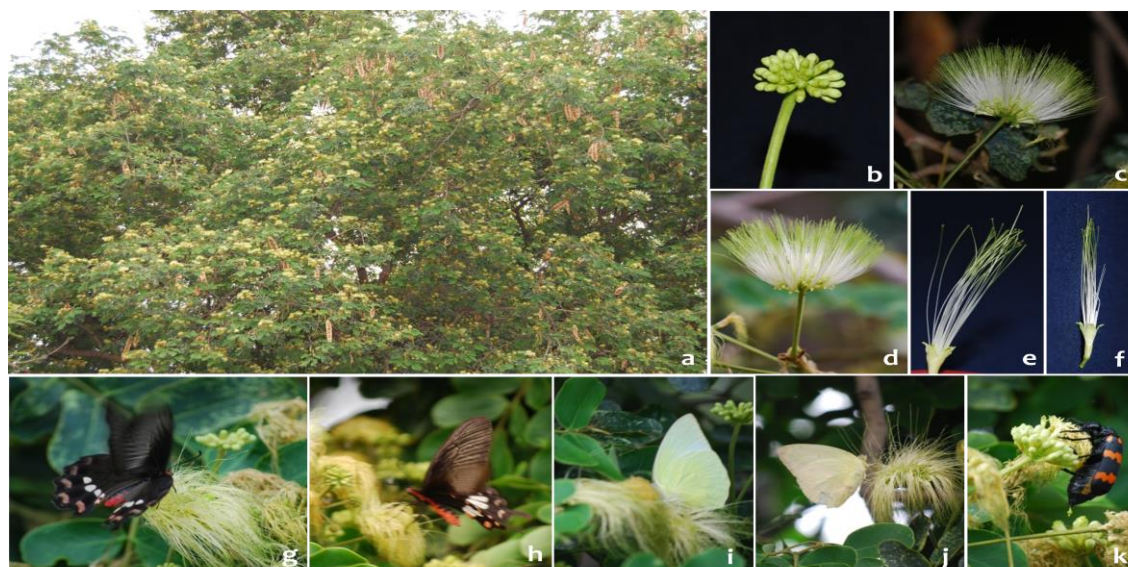


Figure 1. *Albizia lebeck*: a. Tree in flowering phase, b. Buds, c. & d. Flowers, e. & f. Stamens, style and stigma, g. & h. Papilionid butterfly, *Papilio polytes*, i. & j. Pierid butterflies – i. *Catopsilia pyranthe*, j. *Catopsilia pomona*, k. *Mylabris phalerata* feeding on flowers.

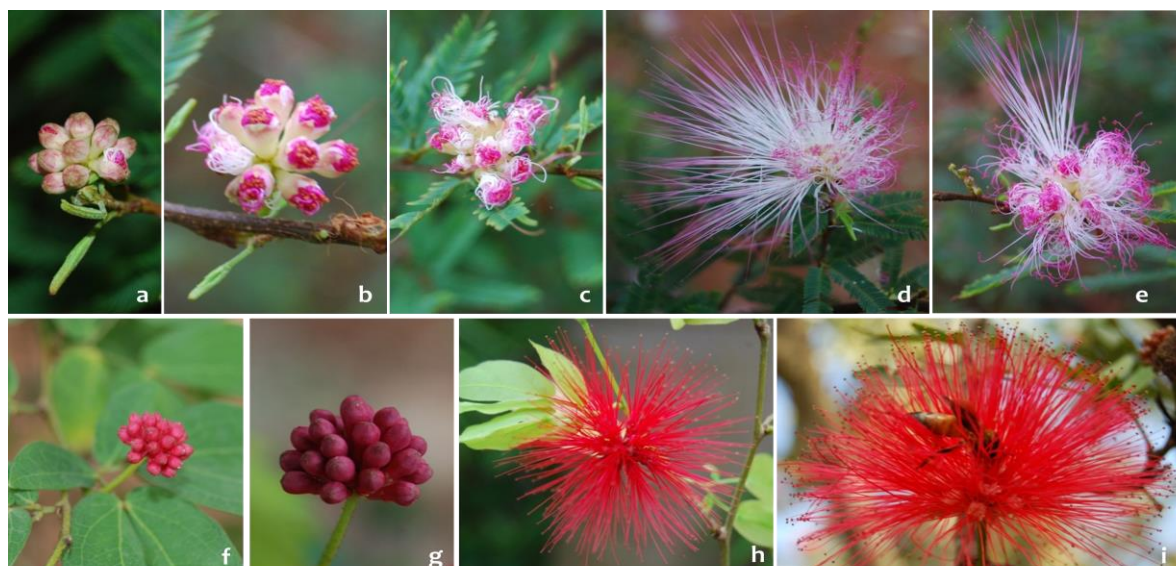


Figure 2. *Calliandra brevipes*: a-d. Anthesis stages of inflorescence, e. Inflorescence with fresh and old flowers; f-i. *Calliandra haematocephala* (cultivated) - f. & g. Inflorescence with buds, h. Anthesed inflorescence, i. *Apis dorsata* collecting nectar.

Calliandra brevipes and *C. haematocephala*: The two species are attractive shrubs with robust growth. The flowering occurs throughout the year but it is intense during February-April. The floral descriptions relate to both species unless otherwise stated. The flowers are borne in puffs in axillary or terminal globose paniculate racemes. The total number of flowers and their functional aspects vary in individual racemes. Bisexual and functional staminate flowers occur in most inflorescences. The blooming of the racemes proceeds from the base to apex but the all the buds rapidly mature and open nearly synchronous (Figure 2a-h). The calyx is cup-like with five deltate teeth. The corolla is campanulate, tubular mostly and apically 5-lobed; it is white in *C. brevipes* and red in *C. haematocephala*. The stamens are numerous, silky, erect and elongate with filaments united into an included staminal tube at base and free later on. They are white basally and purplish red distally obscuring the corolla in *C. brevipes* and entirely red in *C. haematocephala*. The anthers are attached on the back of the filament and their face is spread out from the center of the raceme. They dehisce by longitudinal slits as soon as the filaments straighten at and after anthesis. The pollen is represented by 8-grained polyads per anther and each polyad has two median and six peripheral undivided pollen grains. The basal cell of the polyad has a sticky beak which enables it to attach to the probing insect. The nectar disk is present beneath the ovary and produces traces of nectar. The flowers are open all night and until early morning. Nocturnal moths appear to be attracted to the entire flowering inflorescence which becomes very prominent due to nocturnal folding of the leaves. The ovary is sessile, unicarpellate, glabrous and 8-ovuled with filiform style and dome-shaped stigma.

In both species, the bisexual and staminate flowers offer nectar and pollen as floral rewards to the visitors. The flowers visitors were exclusively honey bees, *Apis dorsata* (Figure 2i), *A. cerana* and *A. florea*. They visited the flowers throughout the day with intense activity during forenoon hours. Since nectar is secreted in traces, these bees concentrated mainly on pollen collection although it also collected nectar. As all the flowers of a raceme bloom synchronously on the same day, it is energetically profitable for the bees to collect huge amount of pollen along with nectar in single visit by reducing flying time and search time for the rewarding flowers.



Figure 3. *Mimosa pudica*: a-c. -a. *Apis dorsata* collecting pollen, b. *Apis cerana* collecting pollen, c. *Apis florea* collecting pollen; d. & e. *Pithecellobium dulce* - d. *Apis florea* probing for nectar, e. Nymphalid butterfly, *Euploea core*; f-h. *Hamelia patens* – f. *Apis cerana* collecting pollen, g. *Trigona iridipennis* collecting pollen, h. Pierid butterfly, *Catopsilia pyranthe* collecting nectar; i. & j. *Mitragyna parvifolia* – i. *Apis dorsata* collecting nectar, j. *Apis cerana* collecting nectar; k-n. *Hugonia mystax* - k. *Apis dorsata* collecting nectar, l. *Apis cerana* collecting nectar, m. *Apis cerana* collecting pollen, n. Papilionid butterfly, *Papilio demoleus* collecting nectar.

***Mimosa pudica*:** It is an exotic invasive prostrate prickly creeping annual or perennial herb which displays flowering during wet season and early winter season. The leaves are petiolate (prickly), bipinnately compound and fold inward and droop when touched or shaken by wind in order to defend them from harm and return back to open state after a few minutes. The inflorescence is an axillary pedunculate globose head consisting of several small pink or purple fluffy flowers which are open synchronously on the same day during 0730-11.30 h. The flowers are mostly bisexual with a few staminate flowers in certain globose heads. The calyx is minute, tubate basally and 4-lobed apically. The corolla is campanulate, 4-lobed and pinkish purple in their upper part. The stamens are 4, exserted and long with pink to lavender filaments tipped with dithecous anthers; they extend far above the corolla giving fluffy appearance and hence they collectively constitute the most prominent part of the flower. The ovary is shortly stipitate and glabrous with 3-4 ovules; the style is filiform with a small stigma which is placed almost at the height of stamens. The anthers dehisce an hour after flower-opening by longitudinal slits. Individual anthers produce several tetrads and are dispersed in the same state after anther dehiscence. Nectar is secreted in traces and placed at the base of the ovary. The flowers were visited exclusively and consistently by *Apis dorsata* (Figure 3a), *A. cerana* (Figure 3b) and *A. florea* (Figure 3c) throughout the day but intense foraging activity was observed during forenoon period. They mainly concentrated on pollen collection due to the presence of negligible quantity of nectar.

***Pithecellobium dulce*:** It is a semi-deciduous medium-sized andromonoecious tree species with branches armed with spiny stipules and bipinnate leaves. Leaf fall and leaf flushing occur in quick succession or partially overlap. The flowering and fruiting event occur year-long in wet areas but peak flowering occurs only during dry season with fruits ripening in 2-3 months after fertilization. The inflorescence is an axillary pedunculate spherical glomerule consisting of 7-18 small, sessile, creamy white and mildly fragrant flowers. The calyx is tubate and enclosed the tubate part of the stamens. The corolla is tubular at base with 5-lobes apically, hairy and soft. Both calyx and corolla are hairy and obscured by stamens. Stamens are white, many with filiform filaments connate into a tube at base and free distally tipped with white anthers. The pollen is a polyad of sixteen pollen grains packed together. The ovary is stalked and bilocular with many ovules; the style is filiform with a small stigma. Nectar is produced in traces only. The flowers were foraged by *Apis dorsata*, *A. cerana* and *A. florea* (Figure 3d) during day time; they visited flowers throughout the flowering season. The flowers with traces of nectar and many polyads serve for the bees as minor nectar source and major pollen source. The butterflies rarely visited the flowers but one nymphalid butterfly, *Euploea core* (Figure 3e) was relatively frequent at the flowers collecting nectar.

***Hamelia patens*:** It is an exotic perennial evergreen shrub. The flowering begins to appear from late summer season and ends in the early winter season. Since it has a long flowering season, it is quite prominent with its attractive flowers produced *en masse*. The inflorescence is pedunculate polychasial cyme with helicoidal branches. The flowers are large, bright orange red, odorless, bisexual and zygomorphic. The calyx has 5 triangularly lobed glabrous limbs while the corolla is narrowly tubular with swollen base and 5-lobed and each each is triangular to ovate in shape. The stamens are 5 and fused to the corolla tube at the throat. The ovary has 2 locules each with numerous ovules. The stigma is fusiform placed at the corolla mouth. The flowers are open during night from 1000 to 0300 h and anthers dehisce ca. 30 minutes after flower-opening by longitudinal slits. The pollen grains are monads and produced copiously in individual anthers. Nectar is produced in moderate quantity and it is placed at the base of the corolla tube. The flowers were visited consistently by honey bees, *Apis dorsata*, *A. cerana* (Figure 3f), *A. florea* and *Trigona iridipennis* (Figure 3g); they collected only pollen from the dehisced anthers which are placed at the throat of the corolla tube. The deeply hidden nectar and long and narrow corolla tube totally prevented the bees to access and collect nectar despite its production in good volume. A pierid butterfly, *Catopsilia pyranthe* (Figure 3h) was a regular visitor to the flowers for nectar collection and it easily accessed nectar through the narrow corolla tube with its long proboscis.

***Mitragyna parvifolia*:** It is a deciduous tree with thick grey colored bark and terete branchlets. The leaves are simple and borne opposite to each other at nodes in decussate manner. The flowering occurs from early March to late June. Mature buds are open from 1830-2100 h with anther dehiscence taking place shortly before anthesis. The flowers are creamy white, fragrant and hermaphroditic borne in terminal pedunculate ball-shaped heads. Individuals heads display asynchronous anthesis with sequential flower-opening on consecutive days for about 3-4 days. The calyx is short-tubed with 5 lobes apically. The corolla is greenish to creamy white with funnel-shaped tube tipped with 4-5 oblong lobes, hairy inside and reflexed. The stamens are 5 with apiculate basifixed exserted and spreading anthers with monad pollen grains, and attached at the apical part of the corolla tube. The ovary is globose and 2-celled with many ovules, filiform style and mitriform stigma. The insect visitors probing the flowers were honey

bees, *A. dorsata* (Figure 3i), *A. cerana* (Figure 3j) and *A. florea* and they visited the flowers during day time from early morning to late afternoon. These bees were effective pollinators as they probed the flowers for both pollen and nectar during which their tongue had physical contact with the floral sex organs. Since the flowers are produced in clusters as heads, the foraging bees reduced flying and searching time for forage collection. A nymphalid butterfly, *Euploea core* was also found to collect nectar from the flowers occasionally during day time, especially during forenoon period and its foraging activity surely effects pollination as it probes the flower with its proboscis through the dehisced anthers and stigma by physical contact.

***Hugonia mystax*:** It is woody climbing shrub commonly distributed in dry scrub jungles and dry deciduous and evergreen forests. The branchlets do not bear leaves at the base but instead there is a pair of recurved spines resembling to a moustach. The flowering is episodic with the production of a few flowers daily and it occurs during wet season. The flowers are borne only on dwarf branches and they anthesse in acropetal succession during 0600-0900 h. They are dimorphic, distylous and self-incompatible. They are hermaphroditic, lemon-yellow, mildly fragrant and nectariferous. The calyx is dark green, pubescent and spatulate with 5 free sepals arranged in imbricate aestivation. The corolla has 5 free lemon-yellow petals which are filamentous at base and enlarged upwards. The stamens are 10, didynamous, monoadelphous and free but have tubular sheath at base. The anthers dehisce by longitudinal slits and the pollen grains are monads. The ovary is 5-carpelled, each with two locules and each locule with one ovule; the styles are 5 and all are equal in length with bifid papillate stigmatic surface. The flowers were foraged during daytime from 0700 to 16:30 h by bees, *Apis dorsata* (Figure 3k), *A. cerana* (Figure 3l,m), *A. florea*, *Trigona iridipennis*, *Amegilla* sp. and *Ceratina* sp. but only the first three species were regular and consistent while other bees were occasional foragers. All these bees gathered both pollen and nectar effecting pollination. Additionally, a Papilionid butterfly, *Papilio demoleus* (Figure 3n) also visited the flowers for nectar collection occasionally.

4. DISCUSSION

Latif et al. (2019) reported that *Albizia lebbek* is pollinated by insects consisting of bees, flies and butterflies of which only the bees such as *Apis dorsata*, *Nomia oxybeloides* and *Amegilla cingulata* act as effective pollinators. The flowers of *A. lebbek* are also speculated to be pollinated by wind; however, the flowers attract bees with their fragrance (Parrotta 1988 and Lowry et al. 1994). In this study, it is observed that in *A. lebbek*, all flowers in a raceme are open on the same day and at the same time during night but nocturnal moths and bats never visited the flowers. Collectively, the flowers of a raceme become more prominent against green foliage even from a long distance to foraging insects during daytime. Further, the floral fragrance and puff-like shape of the racemes enhance attraction to foragers. The pollen is the major floral reward due to production of traces of nectar in each flower. Honey bees utilize the flowers as major pollen source although they collect nectar alternately. A few butterflies use the flowers as nectar source but they do not show flower fidelity to collect nectar. The bees while collecting pollen and nectar in “mess and soil” fashion effect pollination. But, the butterflies probe the flowers systematically for nectar and in this process they also effect pollination. Since bees are involved in pollen collection, they spend more time at each raceme and also spend more time on the same plant switching between racemes in quest of collecting more pollen along with some amount of nectar; their foraging activity mostly contributes to self-pollination by autogamy and geitonogamy. On the contrary, the butterflies spend very little time at each raceme and keep moving between racemes of the same and different trees in quest of more nectar. Such a quick search for nectar between trees facilitates the occurrence of more cross-pollination. A blister beetle is also utilizing *A. lebbek* flowers as its food source but its flower-eating activity is detrimental for the reproductive success of this tree species.

In *Calliandra* genus, the flowers are borne in paniculate racemes and expose the stamens producing polyads in their anthers far above the corolla (MacQueen and Hernandez 1997; Santos and Romao 2008). *C. calothyrsus* and *C. haematoma* var. *correllii* are andromonoecious, the former is pollinated by bats and hawk moths (Chamberlain and Rajaselvam 1996) while the latter is pollinated by a humming bird species (Rathcke and Kass 2003). *C. schulzei* and *C. longipedicellata* are also pollinated by hummingbirds (Arroyo 1981; Hernandez-Conrique et al. 2007); the latter is additionally pollinated by hawk moths, bats and diurnal insects (Hernandez-Conrique et al. 2007). In the present study, *C. brevipes* and *C. haematocephala* are andromonoecious and both bisexual and staminate flowers are borne in the same inflorescence. In individual racemes, the flowers are open synchronously in acropetal succession. The racemose inflorescence with a group of flowers with numerous white-purplish red stamens in *C. brevipes* and with numerous red stamens in *C. haematocephala* attracts the flower-visitors during daytime. In both species, the corolla has no role as an attractant since it is obscured by the well exposed long stamens. Despite the availability of different diurnal and nocturnal insects, only honey bees utilize the flowers of both species as major pollen source and minor nectar source due to production of

huge pollen from numerous anthers produced by racemes. These bees effect largely effect self-pollination by autogamy and geitonogamy because they spend more time at each raceme for pollen collection and then for nectar collection.

Vogel et al. (2005) reported that *Mimosa lewisii* is a hermaphroditic species and pollinated by a nectar-seeking glossophagine bat, *Lonchophylla mordax* during night time but hummingbirds exploit the worn capitula for nectar during daytime. Egbon et al. (2019) mentioned that *M. diplotricha* is pollinated by bees. Silva et al. (2011) reported that *M. bimucronata* is pollinated by hymenopterans, dipterans and coleopterans. Sierra et al. (2009) reported that wild bees collect huge pollen loads of *M. pigra*. Percival (1974) reported that solitary bees use *M. pudica* as pollen source. Raw (1976) reported that the pollen of *M. pudica* is the most common in the pollen baskets of *Exomalopsis globosa* and *E. similis*. Eltz (2001) documented that *Trigona collina* collects the pollen of *M. pudica*. Suwannapong et al. (2013) reported that *M. pudica* pollen is main source for honey bees. Taimanga and Fernand-Nestor (2018) reported that *M. pudica* is pollinated by flies and bees. In this study, it is found that *M. pudica* is andromonoecious and its flowers born in globose heads are pink to purple and open synchronously during forenoon period. The pink to lavender stamens extended far above the corolla and calyx attract only honey bees during daytime and these bees use this plant as major pollen source and minor nectar source. Their foraging activity contributes mostly self-pollination by autogamy and geitonogamy.

Pithecellobium dulce is a tree species introduced into India (Trimen 1894; Khanzada et al. 2013). But, it is not widely cultivated despite its importance as a source of edible fruits. It is pollinated by large and small bees (Brewbaker 1992). In this study, it is found that *P. dulce* is andromonoecious with calyx and corolla obscured by elongate stamens. The white staminal filaments with mild fragrance serve as attractants for flower visitors. The spherical raceme heads with several flowers opening synchronously present copious amount of pollen and minute volume of nectar. The honey bees use this floral source as major pollen source and minor nectar source during the entire flowering season. The flowers also attract butterflies but the latter visit them rarely. However, a nymphalid butterfly, *Euploea core* collects the nectar frequently. Therefore, honey bees are important pollinators for *P. dulce*.

Hamelia patens is self-incompatible (Louis et al. 2012), pollinated by hummingbirds (Collwell 1995; Lasso and Naranjo 2003), and also by butterflies, bees and wasps (Peters 2014). Further, certain birds rob nectar from the flowers of *H. patens* (Lasso and Naranjo 2003). The present study shows that in *H. patens*, the flowers are borne in polychasial cymes. The flowers with bright orange tubate corolla with stamens placed at the throat attract honey bees which visit them consistently until flowering is exhausted. But, the tubate corolla totally prevents the bees to collect nectar and hence they collect only pollen. The tubular corolla with nectar placed at its base is appropriate for nectar collection by butterflies. Although different species of butterflies occur in the study site, only one butterfly *Catopsilia pyranthe* utilized the flowers as nectar source consistently. Therefore, in the study site, the plant is pollinated by pollen collecting honey bees and additionally by *C. pyranthe* butterfly.

In the genus *Mitragyna*, the species are characterized by a dense inflorescence with flowers arranged in compact round heads, fused flowers and ovaries (Razafimandimbison and Bremer 2002). The pollen is partially airborne (Chauhan and Goyal 2006). *M. rotundifolia* is mainly pollinated by bees and butterflies (Kato et al. 2008). In this study, *M. parvifolia* flowers with greenish-creamy white tubate corolla emitting fragrance attract honey bees which are able to collect both pollen and nectar regularly and in doing so, effect pollination. Further, a nymphalid butterfly, *Euploea core* also visits the flowers occasionally to collect nectar during which it effects pollination. Therefore, *M. parvifolia* is almost exclusively pollinated by honey bees.

In *Hugonia* genus, *H. serrata* flowers are tristylous, produce bimorphic pollen, self-incompatible and pollinated by insects (Meeus et al. 2011). *H. mystax* is distylous, self-incompatible and pollinated by *Apis* bees (Raju et al. 1997). This present study also agrees that *H. mystax* is dimorphic, distylous and self-incompatible. The lemon-yellow corolla is the chief attractant to flower visitors which include honey bees, digger bees and small carpenter bees, and also a papilionid butterfly, *Papilio demoleus*; only bees display flower fidelity. The bees while collecting pollen and nectar and the butterfly while collecting nectar effect pollination.

In *A. lebbeck*, *C. brevipes*, *C. haematocephala*, *P. dulce* in the Ingeae tribe (Lewis and Arce 2005) and *M. pudica* in the Mimoseae tribe (Lewis and Arce 2005), the calyx and corolla are obscured by well developed elongated stamens. The flowers are highly aggregated and oriented either vertically or partially horizontally in globular racemes. Since individual flowers are small or minute, the entire raceme elevated by a stalk acts as the unit of attraction for flower visitors. In all these species, the color of stamens is an additional attractant for flower visitors. Of these, *A. lebbeck* is a hermaphrodite species while all others are andromonoecious. In these species the nectar is produced in traces in individual flowers but it amounts to measurable level if the nectar produced by all flowers of a raceme is taken into account. In a raceme, the synchronous opening of all flowers promote visibility and attraction to flower visitors so that the latter can reduce flight time and search time to collect the forage with great ease; it is also profitable energetically for the flower visitors. The pollen grains in *M. pudica* are tetrads, 8-grained polyads in *Calliandra* species and 16-grained polyads in *A. lebbeck* and *P. dulce*. Further, all these species produce a few tetrads/polyads per anther but they form bulk number at raceme level. The production of pollen grains in tetrads or polyads is advantageous for pollen collecting bees since each unit consists of 4 or 16 grains. Additionally, the clustered state of flowers in the raceme facilitate such bees to collect as many pollen units as possible from

several closely arranged flowers in a single visit without spending additional energy expenditure for flight and searching the flowers for forage collection. Seijo and Solis (2003) reported that a single polyad covers the entire stigmatic surface. Nevling Jr and Elias (1971) reported that in *Calliandra*, the germination of a single polyad on the stigma could assure fertilization of all available ovules. These authors also stated the reproductive cycle in this genus seems to be a highly specialized one due to a high correlation of ovule number with the number of pollen grains in the polyads. Silva et al. (2011) stated that polyad condition is seemingly an adaptation to minimize mixed pollen grain loads on the minute stigma. Therefore, the polyad or tetrad conditions provide several advantages not only for *Calliandra* species but also for all other species studied now in Caesalpinoideae.

Louis et al. (2012) reported that *Hamelia patens* is self-incompatible. It is pollinated by hummingbirds (Collwell 1995; Lasso and Naranjo 2003), butterflies, bees and wasps (Peters 2014). Certain birds rob nectar from the flowers of *H. patens* (Lasso and Naranjo 2003). In this study, it is found that *H. patens* is a hermaphroditic species which offers nectar and pollen to flower foragers but the narrow tubular corolla of the flower prevents pollen collecting honey bees to collect nectar and hence they restrict their visits to pollen collection only. The placement of anthers at the corolla throat facilitates the bees to collect pollen with great ease. The flowers individually and their close placement in polychasial cymes collectively provide sufficient attraction to flower foragers. Pollen is produced in copious amount and it could be due to production of monads. Nectar placed at the base of the corolla tube is accessible for collection by butterflies or diurnal moths only. Accordingly, there is only one butterfly, *Catopsilia pyranthe* that uses *H. patens* as nectar source. The closely placed flowers in polychasial cymes facilitate the honey bees and the butterfly to minimize flight time and search time for the floral reward and hence it is economical and energetically profitable for these foragers to collect the forage from *H. patens*. Since a single butterfly species is utilizing the nectar of *H. patens*, most of the nectar remains unutilized and also not re-sorbed. Therefore, *H. patens* appears to be unable to attract nectar seeking visitors despite the production of nectar in considerable quantity and hence it warrants for a chemical analysis of nectar constituents to understand the chemicals responsible for the absence of visits by butterflies.

The genus *Mitragyna* has not been studied for its pollination aspects. Chauhan and Goyal (2006) noted that *Mitragyna* pollen is partially airborne. Kato et al. (2008) stated that *M. rotundifolia* is mainly pollinated by bees and butterflies. In this study, it is observed that *M. parvifolia* flowers produced in ball-shaped heads collectively act as a unit of attraction to flower visitors. The flowers are open during late evening to early night hours but they failed to attract any nocturnal foragers. However, honey bees and a butterfly species, *Euploea core* visit the flowers during daytime, the former while collecting pollen and nectar and the latter while collecting nectar effect pollination. The pollen grains are monads but copious pollen is produced at flower and inflorescence level. Since the inflorescence heads present numerous flowers at a time, it is energetically profitable for the bees visiting the heads to cut down flight and search time to collect the pollen and also advantageous for the flowers to get pollinated in a single visit by the bees. Similar situation holds true in case of the butterfly also.

The genus *Hugonia* is not investigated for its pollination biology despite the occurrence of different species in tropical regions. Meeuse et al. (2011) reported that *H. serrata* is tristylous with bimorphic pollen, self-incompatible and pollinated by insects. Raju et al. (1997) noted that *H. mystax* is distylous, self-incompatible and pollinated by *Apis* bees (Raju et al. 1997). The present study documents that *H. mystax* is hermaphroditic and displays episodic flowering by producing a few flowers daily. The unit of attraction to flower visitors is individual flower as they are large and borne singly above foliage. Further, the pollen grains are monads and pollen is copiously produced in individual anthers. Since the flowers offer both pollen and nectar and provide easy access to any forager, different bees use this plant as both pollen and nectar source. A butterfly, *Papilio demoleus* also occasionally utilizes *H. mystax* as nectar source. Therefore, *H. mystax* with steady state and extended flowering is an important pollen and nectar source for bees.

5. CONCLUSIONS

Albizia lebbek, *Calliandra brevipes*, *Calliandra haematocephala*, *Mimosa pudica*, *Pithecellobium dulce*, *Hamelia patens*, *Mitragyna parvifolia* and *Hugonia mystax* are tropical plants by their distribution range. Of these, *M. pudica*, *M. parvifolia* and *H. mystax* are not planted while all other species except *P. dulce* are planted as ornamentals as part of greenery development in cities. *P. dulce* is an economically and commercially important tree species because its pods are edible and for this reason, it is often cultivated in rural areas. The flowers of all other species have flower value as they draw the attention of human eye. *Calliandra* species, *M. pudica* and *P. dulce* are andromonoecious while the remaining species are hermaphroditic. The reproductive unit of attraction is the raceme/head/polychasial cyme with numerous to several flowers in all these species except *H. patens* and *H. mystax* in which individual flower is the unit of attraction to flower visitors. The pollen grains are either tetrads or polyads in *A. lebbek*, *Calliandra* species, *M. pudica* and *P. dulce*; but they form bulk number at raceme level. These units of pollen grains are advantageous for pollen

collecting bees since each unit consists of 4 or 16 grains. Additionally, the clustered state of flowers in the raceme facilitate such bees to collect as many pollen units as possible from several closely arranged flowers in a single visit without spending additional energy expenditure for flight and search the flowers for forage collection. A single polyad covers the entire stigmatic surface and its germination could ensure the fertilization of all ovules produced in a flower. Further, polyad production could also be an adaptation to minimize mixed pollen grain loads on the minute stigma. In *H. patens*, *M. parvifolia* and *H. mystax*, the flowers produce monad pollen grains but each flower produces copious pollen. All plant species are nectariferous but nectar is secreted in measurable quantity in the flowers of *H. patens* and *H. mystax* while it is secreted in traces in the flowers of all other plant species. All these species are pollinated by honey bees; these bees collect both pollen and nectar from these plant species except *H. patens* from which they collect only pollen due to inaccessibility of nectar. *H. mystax* is pollinated also by digger bees and small carpenter bees. Further, *A. lebbeck*, *P. dulce*, *H. patens*, *M. parvifolia* and *H. mystax* are pollinated by butterflies - *Papilio polytes*, *Catopsilia pyranthe* and *C. pomona* in the first species, *Euploea core* in the second and fourth species, *Catopsilia pyranthe* in the third species and *Papilio demoleus* in the last species. A beetle, *Mylabris phalerata* utilized the flowers of *A. lebbeck* as food by eating the floral parts; its feeding activity is found to be negatively affecting the reproductive capacity of this tree species. Therefore, the present study documents that all these plant species are very important as pollen and/or nectar source for honey bees while some plant species provide nectar to butterflies that visit them which in return effect pollination.

Authors contributions:

All authors contributed equally.

Ethical approval

Flower-insect interactions with reference to honey bees with some plant species (*Albizia lebbeck*, *Calliandra brevipes*, *Calliandra haematocephala*, *Mimosa pudica*, *Pithecellobium dulce*, *Hamelia patens*, *Mitragyna parvifolia* and *Hugonia mystax*) were observed in the study from scrub-jungle habitats of Visakhapatnam city, Andhra Pradesh, India. The ethical guidelines are followed in the study for species observation & identification.

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Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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