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An ecological study of pollination in *Pedalium murex* L. (Pedaliaceae)

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ABSTRACT

Pedalium murex is a common annual succulent herbaceous weed. It grows prolifically during wet season. The flowers are hermaphroditic, homogamous, nectariferous and pollinated by bees and lycaenid butterflies. Flowers are open for a brief period and close back shortly after noontime during which there is a likelihood of occurrence of spontaneous pollination. Highest fruit and seed set rates in open-pollinations enable this weed to migrate through rain water and establishment new populations in new habitats.

Keywords: *Pedalium murex*; hermaphroditism; homogamy; bees; butterflies; weed.

INTRODUCTION

Pedalium is a monotypic genus represented by *P. murex* (Grubben 2004). It is distributed in coastal areas in South India, Sri Lanka, Ceylon, Mexico and tropical Africa. This species is used for the treatment of puerperal diseases, digestive tonics, ulcers, fevers, wounds and general debility (Rajashekar et al. 2012). It is traditionally valued for the treatment of reproductive disorders mainly impotency in men, nocturnal emissions, gonorrhea and leucorrhoea in women; it is also used as a remedy for urinary and gastrointestinal tract disorders (Chaudhary and Kaushik 2017). A melisso-palynological study in the Eastern Ghats forest region indicated that *P. murex* is a minor pollen type for honey bees (Devender et al. 2020). In coastal areas, *P. murex* is a common succulent weed which grows like a crop in open areas and agricultural lands, and also grows intermingled with other herbaceous weeds, especially during wet and winter season. Despite its medicinal values and its ecological role in carpeting the soil, it has not been investigated for any aspect of its pollination ecology. It is in this context, the present study has been contemplated to provided certain details of its ecological aspects of pollination in order to understand its success as a weed through sexual reproduction.

MATERIALS AND METHODS

Pedalium murex growing in undisturbed areas of Andhra University campus was used for study during June 2019 to January 2020. In this campus, it is common in open areas with little vegetation but uncommon in areas occupied by several seasonal herbaceous plants during wet season. In this study, *P. murex* phenology, flowering season, floral biology, foraging activity and pollination, fruiting and seed dispersal aspects were investigated in the field. Protocols described in Dafni et al. (2005) were used to measure nectar volume, record amino acids in pollen, calculate pollen output per anther/flower, and pollen-ovule ratio, and test stigma receptivity. Further, a total of 125 flowers were tagged on different plants and followed for one month to record fruit development period and fruit set rate. Fruit/seed dispersal and seed germination aspects were observed in the field, especially in the wet season.

RESULTS

Plant phenology

It is an ascending stout-stemmed and diffused foetid-smelling succulent deciduous annual herb which grows commonly in coastal areas during wet and winter seasons. The habitats of its occurrence include open sandy soils and agricultural lands. The plant appears profusely during wet season and extends its appearance into winter season depending on the soil moisture status. The plants that grow concurrently in its association include *Merremia tridentata* (Convolvulaceae), *Boerhavia diffusa* (Nyctaginaceae) and *Cleome viscosa* (Cleomaceae) *and Antigonon leptopus* (Polygonaceae) *Triumfetta rhomboidea* (Tiliaceae). *P. murex* alone or together with these plants forms a thick blanket richly covering the ground. Leaves are and produced in opposite and decussate pairs. They are simple, petiolate (3-3.5 cm long), oblong-elliptical to obovate with margins irregularly toothed or lobed with two black glands near the base and apex truncate. Individual plants complete their life cycle within 2 months but at population level, this species displays leaf flushing, flowering, fruiting and seed dispersal events from June to January.

Flowering phenology and flower morphology

Plants initiate flowering following leaf production and the flowering is very profuse during wet season from July to November and sparse during winter from December to January at population level (Figure 1a,b). The flowering usually ceases by early November in plants inhabiting open sandy soils while it extends into late January in plants inhabiting agricultural lands. Flowers are solitary and borne in leaf axils, and stand out prominently above foliage (Figure 1c).

Flowers are pedicellate, 2-3 cm long, pale yellow, zygomorphic and bisexual. The calyx is green, 2 mm long, fused at base forming five linear lobes. The corolla is 2.5 cm long, funnel-shaped with two upper and three lower lobes; the corolla tube is glabrescent but its throat is hairy. Stamens are four, didynamous with two short and two long dithecous dorsifixed stamens and included in the corolla tube (Figure 2c,d); the fifth posterior stamen is short, rudimentary and represented by a staminode lacking anther. The filaments of long stamens are hairy while those of short stamens are glabrous. The ovary is bicarpellary, bilocular syncarpous with a total of 4 ovules arranged on axile placentation (Figure 2j). The style is 1, filiform and tipped with shortly bi-lobed wet and papillate stigma (Figure 2g-i); the stigma is erect and placed either at the height of the anthers of long stamens or slightly extends beyond the height of the anthers of long stamens.

Figure 1. *Pedalium murex* : a. & b. Flowering phase, c. Individual plant with solitary flower.

Figure 2. *Pedalium murex:* a. & b. Buds, c. & d. Position of didynamous stamens in relation to stigma, e. Anthers, f. Pollen grains, g. Ovary, style and stigma, h. Ovary, i. Bifid stigma, j. Ovules, k. Fruit, l. & m. *Ceratina simillima* approaching and reaching the flower base for nectar collection, n. *Chilades pandava* collecting nectar.

Floral biology

Mature buds begin to open slowly from 0530 h onwards (Figure 2a,b) and complete unfolding of the corolla lobes by 0700-0730 h. Anther dehiscence occurs along with corolla-opening; anthers dehisce longitudinally from side walls of the thecae characterizing latrorse type of anther dehiscence. The pollen grains are light yellow, hexacolpate, sticky and 66.4 µm in size; the pollen output per anther is 410.4 ± 10.44 (Figure 2e,f) and per flower is 1641.6 ± 41.76. The pollen ovule ratio is 410.4. The stigma is receptive following anther dehiscence and ceases its receptivity by 1500 h of the same day. The flower secretes trace amount of nectar and it is collected at the base of corolla tube. The pollen contains six essential amino acids and ten non essential amino acids. The essential amino acids are threonine, valine, methionine, isoleucine, lysine and arginine. The non-essential amino acids include alanine, amino butyric acid, aspartic acid, cysteine, cystine, glutamic acid, glycine and hydroxy proline, proline, serine. The total protein content

per 1 mg of pollen is 231 µg. Flowers close back by 1300 h on the day of anthesis. The corolla together with stamens and style and stigma falls off on the 2nd or 3rd day. The calyx is persistent and gives protection in the initial stage of the growing fruit after fertilization.

Foraging activity and pollination

The flowers were foraged by bees, namely, *Apis cerana* (Fabricius, 1793), *A. florea* (Fabricius, 1787), *Trigona iridipennis* (Smith, 1854) and *Ceratina simillima* (Smith, 1854) (Figure 2l,m) and by lycaenid butterflies, namely, *Chilades pandava* (Horsfield, 1829) (Figure 2n), *Zizeeria karsandra* (Moore, 1865) and *Zizula hylax* (Fabricius, 1775). Among bees, *T. iridipennis* and *C. simillima* were consistent and regular foragers while *Apis* bees were occasional foragers. *Apis* bees were unable to access nectar due to narrow corolla tube and hairy filaments of long stamens; they had easy access to the pollen of long stamens compared to that of short stamens. *T. iridipennis* and *C. simillima* had access to nectar that is secreted in traces and placed deep inside at the base of narrow corolla tube; these bees also had to penetrate through the corolla tube with great difficulty to access nectar. These bees, however, had easy access to pollen of both long and short stamens. All butterflies were very occasional foragers and utilized flowers for collecting nectar. Bees and butterflies while probing through the throat of the corolla tube invariably contacted the stigma and the stamens in that order in quick succession and effected pollination. These insects visited many flowers from different plants in the same patch/habitat in a short time due to the production of solitary flowers in each leaf axil and such a foraging behavior was considered to be effecting both self- and cross-pollination but the latter mode was found to be promoted. As the flowers closed back shortly after noon, the foraging activity of these insects was restricted to the forenoon period only.

Floral behavior and pollination

During anthesis, there is almost no possibility for the occurrence of spontaneous autogamy due to spatial separation between the stamens and stigma. Such a situation exists also during short period of open state of flower precluding the occurrence of spontaneous autogamy. But, the shrinking of the corolla tube and closing of the corolla lobes facilitate contact between the stigma and the anthers of long stamens to result in spontaneous autogamy but this mode of pollination is not definite during or after flower closure. The short stamens have no role in spontaneous autogamy as they are placed far below the stigma and below the anthers of long stamens.

Fruiting behavior and seed dispersal

Flowers after pollination and fertilization initiate fruit development immediately. The fruits mature within 3 weeks; they are initially green (Figure 2k) and dark brown when mature and dry. Fruit set rate is 95% in open-pollinations. Fruit is pyramidal, ovoid, four-angled with four extremely sharp spreading 5 mm long spines at the base and conical at the apex. It is indehiscent, 1.59 ± 0.08 cm long and commonly produces 4 seeds. Seeds are black, elliptical to cylindrical, 5 mm long, 1.5 mm broad, mucilaginous upon contact with water, somewhat sweet in taste but lack odor. They are non-dormant, germinate and form new plants if the soil is sufficiently wet and favorable. Seed germination rate is more than 95% during wet season and less than 20% during winter season.

4. DISCUSSION

Pedalium murex is a common herbaceous weed in open habitats and agricultural lands in coastal areas. It shows prolific growth during wet season and sparse growth during winter season. It has the ability to grow well in association with certain weeds such as *Merremia tridentata, Boerhavia diffusa, Cleome viscosa, Antigonon leptopus* and *Triumfetta rhomboidea*. Further, it also has the ability to form thick blanket of population covering the ground due to which soil erosion is controlled in areas of its growth. The plant displays its solitary yellow flowers by presenting them above the foliage in order to attract flower foragers.

P. murex flowers are hermaphroditic with functional male and female sex organs. They are homogamous due to nearly synchronous maturation of male and female parts but homogamy does not facilitate the occurrence of spontaneous pollination during and after anthesis due to spatial separation of sexual organs but there is a possibility for it during the closing phase of the flowers due to shrinking of corolla tube and closing of the corolla lobes. The placement of stigma above the height of long stamens is an indication that the plant is adapted for cross-pollination. The visiting insect foragers also strike the stigma first and then long and short stamens in quick succession in order to access the nectar and in this probing they effect either cross- or self-pollination. As the flowers are solitary, insect foragers are compelled to visit several flowers from different plants in a single foraging bout to satiate their energy requirement from pollen and/or nectar. Such a foraging activity promotes pollination rate and contributes to

enhanced fruit/seed set rate. Bir Bahadur et al. (1986) reported that *P. murex* produces nectar consisting of sucrose and glucose sugars and also α-amino acids. In this study, it is found that *P. murex* flowers produce certain essential amino acids and non-essential amino acids in their nectar and considerable protein content in their pollen indicating that its flowers are important for C_{12} and C_6 sugars for nectar collecting butterflies and bees while they also serve as protein source for pollen collecting bees. As bees exhibit fidelity to *P. murex* flowers, they serve as principal pollinators. while butterflies with their occasional foraging visits serve as minor pollinators. Deepika et al. (2014) reported that *P. murex* is the nectar host plant for the Papilionid butterfly, *Principes demoleus* and the Pierid butterfly *Eurema hecabe*. In this study, *P. murex* has never been visited by these butterfly species. In this context, it is pertinent to state that P. demoleus is a large butterfly and cannot convenient land and forage for the nectar of P. murex flowers. Further, the flower of this plant also cannot satiate the requirement of this butterfly and also energetically not profitable for the butterfly. *E. hecabe* could use the *P. murex* flowers as nectar source but it has not been observed on *P. murex* flowers in this study. Despite carpet-like population growth with prominent floral display, *P. murex* is able to attract a few bee and butterfly species and this situation could be attributable to short-time availability of flowers confined to forenoon period due to closure of flowers after noontime, foetid-smell of the flowers and restricted access by the narrow corolla tube to visiting insects.

P. murex flowers with pollen production in small amount, short period of stigma receptivity and flower closure shortly after noontime indicate that the plant is facultative autogamy but it is largely not functional due to remote possibility for the occurrence of spontaneous self-pollination. The fruit set rate more than 90% in open pollinations indicate that there is a possibility for the occurrence of apomixis because of drawbacks with insect-mediated pollination.

In this study, it is found that *P. murex* produce fruits within 3 weeks. The fruit capsule being indehiscent is unable to disperse seeds while it is still attached to the parent plant. As the plant is a low-ground herb, the mature dry fruits fall off within the vicinity of parental sites and disperse seeds upon decomposition of hard fruit pericarp. The seeds thus dispersed germinate and produce new plants in the same area. Further, the fruits as well as seeds have the possibility to be carried away by rain water for subsequent germination and production of new plants in new habitats.

CONCLUSIONS

Pedalium murex is an annual succulent herb that shows carpet-like growth in open habitats due to which soil is well protected and soil erosion is controlled. It is a prolific weed during wet season and provides nectar for certain lycaenid butterflies and pollen as well as nectar for certain bees. The plant is both bee- and butterfly-pollinated. Highest fruit and seed set rates in open-pollinations are indicators of the reproductive success of the plant through sexual reproduction and enable the plant to grow as a successful weed.

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Authors contributions

Both authors contributed equally.

Conflict of interest

The author has no conflict of interest to declare that are relevant to the content of this article.

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Data and materials availability

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

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