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Full Length Article

Effective Pollinators by Chinese Honeybee and Bumblebee in *Paphiopedilum malipoense*

Guole Qin[1], Quan Yuan[1], Daizu Xie[2] and Chenyu Shi[1*]
[1]*Institute of Chemical and Biological Engineering, Hechi University, Yizhou 546300, China*
[2]*The Forestry Department of Hechi, Nandan 547204, China*
[*]For correspondence: shichenyu521@163.com

Abstract

The population distribution and pollination biological characteristics of *Paphiopedilum malipoense* in the Mulun karst forest region were studied by recording insect flower visitations, identifying powdered species, observing flower morphology and recording flowering plants. The primary goal was to reveal the pollen transmission mechanism and evolution of *P. malipoense*, and to provide a basis for protecting *P. malipoense* in the Mulun National Nature Reserve in Guangxi, China. The results showed that Chinese bees and bumblebees were effective pollinators of *P. malipoense*, and it was speculated that *Paphiopedilum* might attract Chinese bee and bumblebee to transmit pollen through the small purple spots that serves as false honey guides on their lips. It is suggested that bees use a food-borne deceptive transmission with a success rate of 33.3%. These results of may provide basic data for the formulation of conservation measures of this species in Mulun National Nature Reserve of Guangxi.

Keywords: *Paphiopedilum malipoense*; Quadrat survey; Pollinology; Pollination behavior

Introduction

Paphiopedilum malipoense s. c. Chen, et z. h. Tsi is refered to as *Paphiopedilum*. This species is one of the most primitive types of orchids, and has been listed in the Convention on International Trade in endangered species of wild fauna and flora (Convention on International Trade in Endangered Species of wild Fauna and Flora, CITES) appendix I. Trade of the wenshan-malipo strike-slip pocket orchid is prohibited by the wild resources of Species (Cox *et al.*, 1997; Lang *et al.*, 1999).

Bee pollination has many advantages, which is safe and efficient, and does not injure flowers, and the number of bees is large. It is beneficial to the stability of wild resource community ecosystem because of its co-evolution and mutual benefit in pollination behavior. At the same time, there is a need to increase the economic importance of the species surveyed. *Paphiopedilum* is a perennial evergreen herbaceous plant of *Orchidaceae*. It has large, and long blooming flowers, which is very rare wild species. Thus, it has great potential for market demand and is therefore worthy of development and production. The artificial pollination technology of wild *Paphiopedilum* spp. has high requirements and high cost, and insects are undoubtedly the best pollination choice. It is of great significance for the development of wild resources and orchid industry to study the mechanism and model of wild resource and orchid industry (Tan, 2009).

In recent years, *P. malipoense* or its hybrid has won many horticultural used around the world because of having high ornamental value. The ornamental value of these plants has led to excessive mining. *P. malipoense* and Apricot do not bear rhizomes. In the natural habitats, the population of *P. malipoense* is distributed in 400-600 m above sea level, in the areas with thick under the forest humus and moist stone seam soil (Zhong *et al.*, 2002).

At present, the pollen transmission mechanism of Orchidaceae is mainly reported in Europe, North America and South Africa. There are only few studies on the pollination biology of Orchidaceae in Asia, especially for *P. malipoense* (Schiestl, 2005; Jersakova *et al.*, 2006; Kaiser-Bunbury *et al.*, 2017; Petanidou *et al.*, 2018.). In this study, pollen transmission mechanisms of *P. malipoense* was explored by observing the pollen vector and flowering plants, and results are used to provide protection and development strategies for this species.

Materials and Methods

Research Site

Mulun national nature reserve is located in north Guangxi, in the Chuan Shan karst area. The northern areas of the Guangxi reserve are adjacent to the Guizhou Maolan national nature reserve. The geographic coordinates of the

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reserve is 107°53'29"~108°05'45" E, 25°~25°12 '06'09"25" N, 20.6 km long, north and south 11.6 km wide, with a total area of 10829.7 hm^2. The area is a subtropical monsoon climate zone, with an average annual rainfall of 1530~1820 mm, annual average temperature of 15.0~18.7ºC, extreme high temperature of 36ºC, and extreme low temperature 5ºC. The forest is wet, relative humidity is high (80~90%), and the humidity can reach saturation in the summer months. The protected forest area covers 9991 hm^2, with a forest coverage of 93.4%, and this forest is a subtropical limestone forest ecosystem, and the Maolan Nature Reserve in Guizhou constitutes the largest and best preserved limestone evergreen and deciduous broad-leaved mixed forest ecological system in the world (Tan, 2009). This study was conducted on the orchid mountain in villages along the Huayang Mountain, including the Maoism and Mui villages, in the Guangxi nature reserve. Pollination observations were carried out in the Huayang Mountain near the three jute chestnut hills, which are located in the village of Ming-tuo Mun.

Research Methods

Sampling method: Samples were collected on March 2011 in the protected areas. The center of the wenshan-malipo strike-slip pocket LAN distribution points were set up for 10 × 10 m^2 quadrat surveys, and middle of each sample, altitude, latitude and longitude, slope direction and plant level, number of or around the abundance, type, diameter at breast height, coverage, forest type, and rock type were measured.

Pollination observations: Observations were carried out between April 11, 2011 to April 20, 2011 at 7:00-19:00 for the Guilan population of Malipo, Mouli Village, Minlitun Kairong Mountain, and Mouli Village, as well as the Guolan population of Malipo. Cameras, insect nets, tweezers, and photography were used to capture insects. The time when flowers were visited, the number of insects, the insect species and the number of flowers visited by the same insect were recorded throughout the day. The behavior of the insects visiting the flowers was measured by whether they brought pollen or not, and how long the pollinator stayed on the flower. The insect was quickly captured and placed in 95% ethanol to identify the species.

Results

Sample Survey

Observations were made in evergreen and deciduous broad-leaved mixed forest, and the dominant tree species were *Melia azadirachta*, Qingxiang wood, fish bone wood, and *Loropetalum chinense*, with a coverage of 35~60%. The shrubs are mainly azedarachta, petalopetalum, crude chlamywood, false yellow skin and other tree species, and the coverage is 17~52%. The herbaceous layer is mainly spider holding eggs, cold water flowers, comb cap roll orchid, fragrant aconite, and the coverage is 10~45%. The dominant species are *Azadirachta azedarach* trees, clear fragrant wood, petalopetalum wood, spider holding eggs, and cold water flowers. Plant species that are found in this area are commonly found species in the Mulun nature reserve, and there is no significant difference in species distributions. It is speculated that tree species may not be the decisive factor for the distribution of *P. malipoense*.

Types of Pollinators and their Behavior

Insects that were observed on the orchid flowers for pollination behavior included fly (*Musca spp.*), Chinese bee (*Apis cerana*), and bear (*Bombus spp.*) insects (Table 1). Pollination behavior was observed when it was sunny, and similar behaviors were observed during the day. Specifically, the following three types of insect behavior were observed: (1) Some insects may be attracted to the scent or the color of flowers when they are active, and sometimes they are randomly approached sepals, petals, or lip petals, but not the lips of the flowers. This behavior likely does not represent those of effective pollinators. Insects that behaved in this category were flies (*Musca spp*.), *Coreidae spp.*, and *Traulia spp*. (2) Some insects accidentally dropped into the lip, but due to their small size, did not come in contact with pollen. They generally did not visit the flower again, and included ants (*Anoplolepis spp*.) and *L*ycosidae spp. (3) When Chinese bee or *Bombus spp*. approached the maroon, they hovered for 2-3 seconds in front of the flower, and flew into the lip flap of the capsule.

Insects searched for pollen in the flower and crawled back and forth in the labial flap to escape, but due to the eaves in the entrance, they did not escape from the original entrance. After several failures, they entered the pollination passage that consisted of the lip and the columnar column. They first squeezed through the stigma, and escaped from the opening near the stamen. During this process, the pollen stuck on to the back of the pollinator's thorax as it kept wriggling. After climbing out of the flower, the insect soon left. When it revisited the nearby valley and repeated the process, it stuck the last pollen to the stigma, the average amount of powder carried by *A. cerana* and bumblebee was 80-260 mg. After 3 months, the results of pouch orchid after visiting flowers and bagging showed that the pollination was successful. However, only a small number of visitors with larger size can escape through multiple attempts at climbing and moving into the channel. When the insect climbed upward, their body touched the pollen, which is found in a sticky clump on the bottom of the capsule. When the insect touched the stigma when climbing upward again, the orchid was self-pollinated. However, self-pollination through an insect was rare. Pollinators carrying the orchid’s pollen also visited other flowers, enabling cross pollination.

These observations showed that only Chinese bees and bumble bees pollinated wenshan-malipo strike-slip pocket LAN, with the Chinese bee completing most successful cross

Table 1: The activity of insects visiting flowers

Species	The number of insects near the flower	The number of insects exposed to degenerated stamens	The number of insects entering the labial lobe	The number of insects with pollen
Musca spp.	23	0	0	0
Apis cerana	8	7	6	5
Bombus sp.	5	4	3	3
Coreidae sp.	1	0	0	0
Traulia sp.	1	0	0	0
Anoplolepis sp.	2	2	2	0
Lycosidae sp.	1	1	1	0

pollination events. The bumblebee rarely had an effective second visit. The activity of insects visiting the orchid flowers are summarized in Table 1. Some of the insects and their behavior when visiting flowers are shown in Fig. 1.

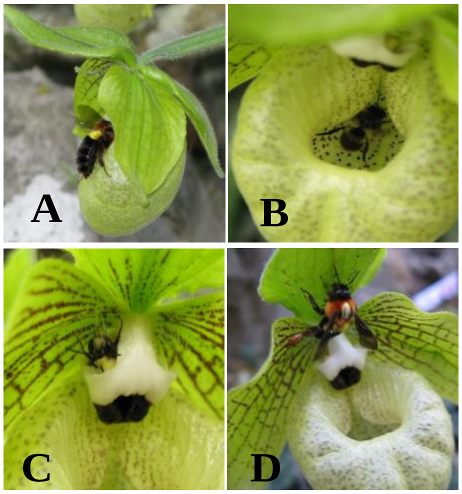

Fig. 1: Behavior of insects visiting the flower
A. Bumblebee docked directly at the entrance to the lip; B. Chinese bee trapped in the lip flap. C. The Chinese bee moving to escape the flower from the side of the stigma; D. A bumblebee that successfully escaped from the flower, with flat banded pollen adhering to the back of the thorax

Observation and Analysis of Flower Morphology

P. malipoense is mostly clustered, with short fleshy rhizomes that are hairy. Leaves are basal; two-row; leathery, with dark-green grid spots on the surface and purple spots on the back. Flowering period is from mid-March to the end of April for about 50 days. The scape is slender and erect, usually more than 30 cm. The terminal flower is 8-9 cm in diameter, yellow-green, with purple-brown stripes on petals and middle sepals or more stripes composed of spots. The lip is deep saccular, subglobular, with purple-brown spots. The entire perianth has a waxy reflection, and has a strong fragrance. Staminodes are round oval, white, with dark purple patches near the apex, and flowers do not have typical synanthetic style structure. Pollen is yellow sticky pollen cluster, which is different from the general scattered pollen or the pollen block structure of most orchids, and does not have the anther cap and pistil beak commonly found in most orchids. The pistil beak is a unique organ of Orchidaceae plants. It is a layer of sticky substance that sticks to insects when they pollinate the plant and help insects take away pollen blocks from Orchidaceae plants. The pollen mass of *P. malipoense* is viscous and adheres to the body of pollinating insects, playing a role similar to the pistil-beak. The pollen that adhered to the body of the pollinator was flat and banded. The pollinators did not take all the pollen from the pollen mass when they visited the plant. That is to say, the pollen mass structure can support more than one pollination visit. Therefore, if the visiting insect successfully takes the pollen away, there will still be more pollen in the flower for another individual to take the pollen away. Most orchids have the pollen mass-coracoid structure even if the pollen of the flower is taken away completely during the first insect visit. The viscous pollen assemblage structure of *P. malipoense* may improve the potential utilization rate of reproductive input to some extent.

Analysis of the Flowering Plant

By observing the flowering plant in the vicinity of the jute kuropoa colony, we found that there were many flowering plants during April 2011, and many were orchids. However, no flowering plants with similar size were found in the same period, which was similar to Anthophyllaceae (*Echinacanthus lofouensis* (Levl.) j. r. i. Wood) of Acanthaceae. Anthophyllaceae is a shrub that is about 3m high, and its flowers are pale yellow with a brown stripe (Fig. 2). However, the yellow flowers have no fragrance, and the maroon, chestnut, is one of the few species of the genus, which can use flowers to attract insects for its pollination. The flowering plants in the same period near the population of *P. malipoense* are shown in Table 2. Also the structure of the medicine cap, pollen block and stamen beak of the orchids that bloom at the same time is shown in Fig. 3. In January 2012, fruit setting was recorded at the observation point. The results showed that all flowers that bore fruit normally had records of Chinese bee or bumblebee visiting the flowers.

Discussion

The cystic lips and the pollination channel are features of the genus cylon that serve as a "trap" for the pollinators (Dressler, 1993; Cribb, 1998). Through the distinct morphology of the labial and sepals, orchid flowers can be

Table 2: Comparison of characteristics of flowering plants in the same period

Species	Flower color	Many degrees
Pilea sp.	Pale yellow	Cop3
Bulbophyllum violaceolabellum	Purple spot	Cop1
Cheirostylis chinensis	White green heart	Un
Coelogyne flaccida	White yellow lip	Cop2
Cymbidium ensifolium	Green and yellow	Sp
Eria rhomboidalis	Red flower white lip	Sol
Eria clausa	yellow	Sol
Liparis viridiflora	Pale yellow	Sp
Vanda concolor	Orange	Sp
Echinacanthus lofouensis	Pale yellow	Un
Aspidistra sp.	purple	Cop1

The order by quantity is as follows: Cop3, Cop2, Cop1, Sp, Sol, Un

Fig. 2: Yellow flower rock flower structure
The corolla of the flower was torn open, revealing the visible petal ventral chestnut spot

divided into two categories: the curtilage type and the orchid type. Wild type flowers (such as hard leaf pocket orchid *P. micranthum* t. Tang et f. t. Wang, apricot yellow pocket *P. armeniacum* s. c. Chen, et f. y. Liu) are similar to most wild flowers, where the sepals are usually small, where their lip for margins are curled inward spherical or near spherical capsule. This type of flower is mainly pollinated by bees (Liu *et al.*, 2005; Shi and Cheng, 2007). Pocket orchid flowers, such as the purple hair pocket orchid *P. villosum* (Lindl.) Stein, and ribbon pocket *P. parishii* (Rchb. F.) Stein, long flap pocket *P. dianthum* t. Tang et f. t. Wang, have sepals that are usually larger, lip to edge upright helmet capsule. The pocket orchid flowers are usually pollinated by aphid flies (Atwood, 1985; Bänziger, 1994; 1996; 2002; Shi and Cheng, 2007). Apricot yellow pocket in the wild type flowers use false stamens with puce markings and maroon spot lip to emulate the food source plant of the pollinators. Foodborne cheating pollination is the ability to rely on the insect's sense of smell at a distance (Cribb, 1998). There are also differences in the patterns of flowers that attract pollinators. Those that rely on simulated sources of food to deceive pollinators (such as *Aristolochia purpurea*) have yellow stamens and attract pollinators by simulating honey beads, pollen or other foods (Bänziger,

Fig. 3: Orchid cap-pollen mass-corona
The pollen block adhered to the tweezers on one end of the core beak

1994; Bänziger, 1996; Shi and Cheng, 2007). Those with green stamens and black protrusions or hairs on petals or labial petals (such as *A. longifera*) rely on simulated breeding sites to attract pollinators. The protrusions on petals or lips attract female aphids to lay eggs by simulating aphids, which serve as a food source for aphid larvae (Bänziger, 1996; Waser, 1996; Armbruster, 1999).

We observed that there were seven species of insects in the community of *P. malipoense*, and only the Chinese bee and bumblebee were the effective pollinators of *P. malipoense*. Although these insects belong to different species, the behavior of carrying pollen, taking away pollen and transmitting pollen is the same. Therefore, they can be placed into the same functional group (Waser *et al.*, 1996; Armbruster, 1999; Fenster *et al*., 2004). In other words, the pollen transmission of *P. malipoense* is a special pollen transmission system.

Orchids often reward pollinators with nectar or lipids (Vander and Dodson, 1969; Ackerman, 1986; Nilsson, 1992). However, we did not find any rewards for the pollinators in the wenshan-malipo strike-slip pocket orchid. Therefore, we speculate that the jute chestnut is relying on the deception strategy to complete pollination. The bees that were captured on the orchid were females; therefore, we did not find evidence of sexual deception (Schiestl *et al.*, 2003). Wenshan-malipo strike-slip pocket orchids did not have analog parts of the insect. Therefore, we believe that there is no sexual cheating system in this species.

In the orchid plant, foodborne cheat pollination can be divided into two kinds: one stimulates food through shape or color, and the other that flowers during the same period (mimicry) (Dafni, 1983; Nilsson, 1983; Johnson, 1994). We did not find sufficient evidence to show that the wenshan-malipo strike-slip pocket orchid simulate other flowering plants to attract pollinators. The only species that appeared similar to the wenshan-malipo strike-slip pocket orchid was the *Angiospermae chrysanthemum* rock flower. Previous studies (Anderson Johnson, 2006; Juillet *et al.*, 2007) have shown that flowering at the same time can benefit or harm deceptive orchid plants. However, it is necessary to further study the flowering plants in the vicinity of the study area.

Another kind of foodborne cheat pollination is to attract pollinators through color and form (Boyden, 1982; Nilsson, 1983). Although the habitat is relatively dark, there were many large and bright flowers, which can effectively attract pollinators. Some studies have shown that bumblebees are usually attracted by visual signals at a distance, such as the color and size of flowers. In close range, bumblebees rely on scent to adjust their approach (Giurfa and Legrer, 2001; Raguso, 2001; Boyden, 1982). Many field-based experiments have shown that deceptive orchids and simulated patterns increase the chances of pollination for deceptive orchids (Gtmbert, 2000; Gigord *et al*., 2002; Johnson and Morita, 2006). In the course of our observation, the flowers had a faint fragrance, especially on sunny days. However, it remains to be seen whether the fragrance affected the behavior of bumblebees. There were spots on the corolla of some of the mordant plants, known as the honey guide, which can attract insects (Zhang, 2005). Bees visited directly down the lip of the Wenshan-malipo strike-slip pocket orchid where there are small spots, suggesting that these spots may serve as a false honey guide to attract the pollinators.

The flowers of *P. malipoense* have similar characteristics to many heterogeneously powdered plants, such as bright corolla, lip and stamens, which appear after blooming. However, according to the behavior of its pollinating insects, it has the characteristics of transition type between heterophore fertilizing and self-anthesis fertilization. These kinds of plants can undergo both hetero- and self-anthesis fertilization at the same time, taking part in a variety of reproductive success strategies, which not only produce some distant progenies with genetic diversity, but also produce some inbred offspring. We observed that the number of flowers in the population of *P. malipoense* was small, suggesting that self-flowering and pollination was also a self-protection mechanism, which may play a role in times when cross-flower pollinators do not visit the flower or for when the number of flowers in the area was insufficient.

It is now generally thoughts that self-pollination is a secondary trait, and has evolved from a primitive hetero-pollen species at the species or genus level (Vasek and Weng, 1988). Orchidaceae is a large family of animal pollinators that are monocotyledons, and the diversity of *P. malipoense* flower morphology indicates that it has a variety of pollinators. The jute chestnut has distinctive yellow green corolla and the rich floral aroma, indicating that it is pollinated by insects. Each plant only produces one flower, which indicates the possibility of high heteroties (Schemske, 1983). The cystic lips indicate that it is associated with pollinators susceptible to deception. All of these characteristics indicate that *P. malipoense* is pollinated by insects. According to the results this study, pure cross-pollination visitors are not dominant in the natural population of *P. malipoense*, and there are more self-pollinators or those that are pollinated by insects and self-pollinated. The pollinator limitation of *P. malipoense* may be due to the lack of insects or the fact that the life cycle of insects does not synchronize with their flowering phenology. These species may experience limited pollinator conditions, where self-polination can improve pollination efficiency. Consequently, natural selection is conducive to reproductive strategies with more reproductive security, rather than relying entirely on pollinators when pollinators are unreliable. This hypothesis may be an explanation for the cross-pollination and self-pollination of *P. malipoense*. We speculated that some of the larger insects may accidentally drop out of the lip and take out pollen. However, such incidents were not observed, and the insects did not visit the flowers again, thus the flowers were not pollinated.

Some of the characteristics of *P. malipoense* exacerbate their extremely endangered state: there are nearly 200 *P. malipoense* plants in the population of Haodong Mountain in Jiutun, Shecun, yet only seven flowers were produced in 2011. Several populations of *P. malipoense* in the vicinity did not even blossom this year, indicating that the plants of this species grew poorly. We found that it takes about half a year on average for *P. malipoense* to fully unfold its flower buds. During this period, the reproductive growth of *P. malipoense* is terminated if insects begin to gnaw at the flowers.

The foodborne and pollination system of *P. malipoense* appears highly asymmetric, where the flower is more dependent on the pollinator, as the flower does not contain any rewards for the pollinator (Dressler, 1993). However, *P. malipoense* only cheats insects to pollinate by attracting insects through the color and fragrance of their flowers. Native bee populations are declining due to invasive bee species, and plants that are primarily pollinated by native bees are threatened (Xie and Wu, 2004). Therefore, in addition to protecting the *P. malipoense*, conservation efforts should also focus on the pollinators, as well as protecting the food source of the pollinators.

Conclusion

The morphological characteristics of the flowers in *Paphiopedilum* sp. were different, and there were also differences in the patterns of attracting powders. We observed that there were seven species of insects in the community of *P. malipoense* in the wild. Only the Chinese bee and bumblebee were the effective pollinators of *P. malipoense*. No such substances were found in the *P. malipoense*, which could be used as a reward for Chinese bees and bumblebees, and no pollen feeding behavior was observed. The female worker bees of Chinese bee and bumblebee we catch are different, while the position of carrying pollen, the behavior of taking away pollen and transmitting powder is the same. It was implied that *P. malipoense* depends on deceptive strategy to complete the transmission of pollen.

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