

BEE POLLINATION IN *CALANTHE TRICARINATA* LINDL. (ORCHIDACEAE)- AN ENDANGERED ORCHID FROM NORTHWESTERN HIMALAYAS

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Abstract

Non-rewarding plants employ a variety of deceptive strategies to attract their pollinators. One of the least understood of these is generalized food deception, in which flowers exploit non-specific food-seeking responses in their pollinators. Available evidences suggest that colour signals, scent, and phenology may all play key roles in this form of deception. Presently, pollination system of a non-rewarding orchid species, *Calanthe tricarinata* Lindl. has been investigated. *Calanthe tricarinata*, commonly known as *Monkey Orchid* is an endangered orchid of NorthWestern Himalayas; it is popularly known for its beautiful flowers and its leaves and pseudobulbs are used for curing sores and eczema. There are no reports so far concerning the pollination of this species. The current study, which combined field observations and pollination experiments, was conducted to gain further insight into the reproduction of this important orchid species. During the present investigation, western honey bee, *Apis mellifera* (Order: Hymenoptera; Family: Apidae), was found to be an effective pollinator. Since, the transfer of pollinarium, from anther to stigma, took place through the frontal surface of the head of the pollinator bee, the mode of pollination is *Frontotribic*. However, pollination experiments also revealed that this species was self-compatible, but allogamous. The fruit set for the open-pollinated flowers was observed as very low, suggesting thereby a high degree of pollinator limitation, possibly as a result of the deceptive nature of this species.

Introduction

THE FAMILY Orchidaceae is one of the most advanced and largest families of angiosperms comprising of about 28,484 species (Govaerts *et al.*, 2017), and has always been interesting to evolutionary biologists because of its remarkable floral forms and diversity in pollination systems (Darwin, 1877). In India, the Eastern Himalayas (including the NorthEast India), the Western Ghats, and the Western Himalayas are the three major centers of orchid diversity, with a total strength of about 1,256 species of orchids in 155 genera (Singh *et al.*, 2019). The great geographic expanse of the country encompassing a variety of bioclimatic zones and the enormous diversity of ecosystems account for the bewildering array of orchid species in India. The tremendous floral diversity and evolutionary radiation of orchid species is often linked to their intimate pollinator relationships with 60-70% of orchid species being dependent on discrete pollinator lineages or even single species (Cozzolino and Widmer, 2005). The highly specialized reproductive organs and exquisite structure adapted to insect pollination are amazing. The mutual beneficial relationship between plants and pollinators is common in ecosystems (Pal *et al.*, 2019). However, a considerable number of angiosperm species do not provide rewards for pollinators, and have instead developed deception mechanisms to allure insects to visit their flowers and these insects complete pollination

process without receiving anything, in return. This is known as deceptive pollination (Goodrich and Jurgens, 2018). No-reward pollination mechanisms have been recorded in at least 32 angiosperm families, including 7,500 species, of which 6,500 belong to Orchidaceae (Jersakova *et al.*, 2006). Such a large number of deceptive pollination species being concentrated in one family has attracted much attention from a diverse range of researchers in plant systematics, pollination biology, and evolutionary biology (Renner, 2006; Schiestl, 2015). Nearly one-third of Orchidaceae plants rely on deceptive pollination, which might be one of the important reasons for the diversity of orchids (Stokstad, 2015). The orchids use or manipulate insect behavior, including foraging, mating, oviposition, and inhabiting, and have evolved various deceptive pollination mechanisms. Common types include generalized food deception, batesian mimicry, sexual deception, oviposition mimicry, and habitat mimicry, of which the first three are the most common (Cozzolino and Widmer, 2005; Scopece *et al.*, 2010, 2017). Generalized food deception refers to the fact that orchids provide false food signals to insects, such as false pollen or spur without nectar, to trick insects to forage on flowers, and complete the process of pollination. If the orchid mimics a particular rewarding and synchronized flowering plant, this deception is termed batesian mimicry. Sexual deception in orchids involves the use of insect mating behavior by sending false female sex

hormones and morphological signals, attracting male insects to mate, to achieve the purpose of pollination. In sexual deception, orchid pheromones play a key role in attracting pollinators (Jersakova *et al.*, 2006).

The orchid flowers exhibit both biotic and abiotic modes of pollination (Buragohain and Chaturvedi, 2016; Pal *et al.*, 2019), and they show high specificity for their pollinators (Tremblay *et al.*, 2005). Although, this specialization greatly enhances the pollination efficiency of orchids (Nilsson, 1992), but it often results in very low rate of pollination. Although, various groups of pollinators of orchids have so far been reported, 60% of these orchids are pollinated by the insects belonging to order Hymenoptera (bees, wasps, and ants) alone (Brodmann *et al.*, 2008; Prakash and Pathak, 2020; Sugiura, 2013), and rest 40% of these are pollinated by the other groups of biotic pollinators in the orders Lepidoptera, Diptera, Coleoptera, Orthoptera *etc.* like beetles, flies, butterflies, moths, crickets *etc.* including birds and even mouse (Jersakova and Johnson, 2007; Johnson, 1996; Micheneau *et al.*, 2010; Peter and Johnson, 2014; Sun *et al.*, 2014; van der Pijl and Dodson, 1966; van der Niet *et al.*, 2011; Wang *et al.*, 2008).

Presently, the studies have been made on pollination biology of *Calanthe tricarinata* Lindl. (commonly known as *Monkey Orchid*), an endangered orchid of NorthWestern Himalayas. *Calanthe* is an important genus in Orchidaceae with high ornamental and medicinal value and comprises approximately 200 species of primarily terrestrial or lithophytic orchids distributed throughout Africa, Madagascar, China, Japan, tropical Asia, and Australia (Suetsugu and Fukushima, 2014). With the continuing deterioration of the ecological environment, many species are on the verge of extinction (Huang *et al.*, 2015). Thus, it is important to conserve these plants in their natural habitat. Although, *in vitro* propagation of this taxon has been studied by a few authors (Godo *et al.*, 2010; Wang *et al.*, 2018), resulting in the successful production of seedlings, the reports about its pollination system in its natural habitats are scarce.

Since, *C. tricarinata* is medicinally very important and used to cure sores and eczema (Devi *et al.*, 2018; Kumar *et al.*, 2018, 2019; Kumari and Pathak, 2020; Pandey and Bhatt, 2021; Pathak *et al.*, 2010; Prakash and Pathak, 2019), its natural populations are decreasing at an alarming rate due to ruthless

collections and over-exploitation. Hence, there is an urgent need to conserve this endangered species and protect its survival in natural habitats. Therefore, the present studies on pollination biology of *C. tricarinata* were undertaken with a view to identifying the pollinators and developing the alternate strategies for pollination so as to conserve the species in its natural localities.

Material and Methods

The Study Site

The field observations on pollination biology of *Calanthe tricarinata* were made in Narkanda hill station of Shimla district, Himachal Pradesh, India, during June to August, 2018. Narkanda hill station is located at 31°16'12.00" N and 77°27'0.00" E, at an average elevation of 2400-2700 m amsl. The area is dominated by a large temperate forest mostly consisting of Conifer, Oak, Maple, *Populus*, *Aesculus*, *Corylus*, Holly *etc.* species. Apart from these trees, there are various shrubs like *Berberis aristata* and flower plants growing in the area. Recently, the forest has been cleared for the apple orchards.

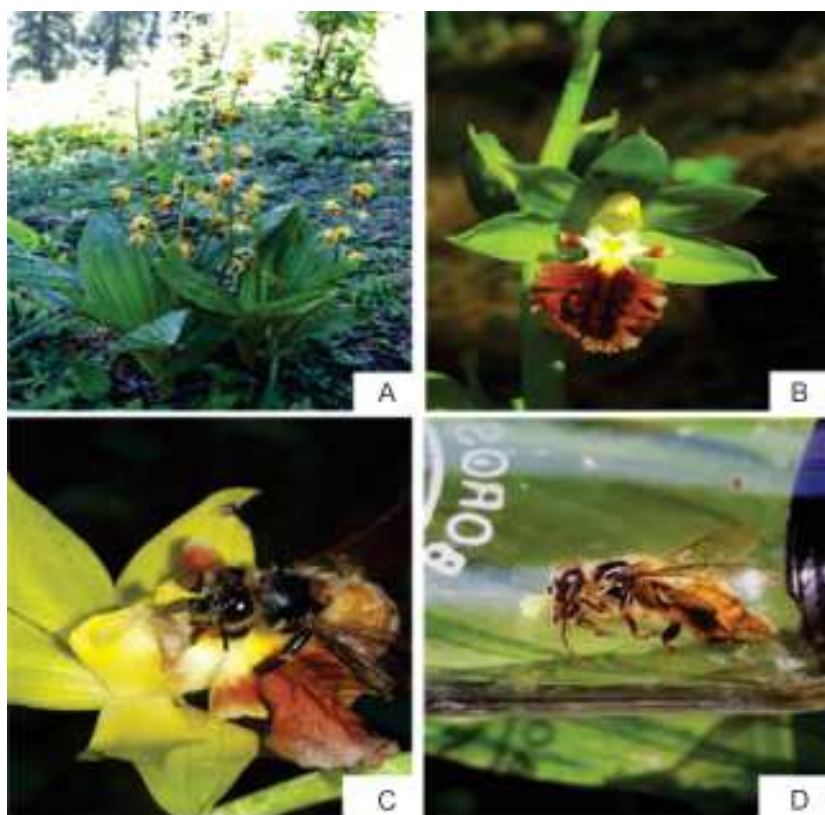


Fig. 1. A-D. Bee pollination in *Calanthe tricarinata*: A, Plant in its natural habitat; B, Close up of the flower; C, *Apis mellifera* loaded with pollinia; D, *A. mellifera* captured and killed in fumes of ethyl acetate.

The field observations of the pollinators were made mainly between 9 am to 3 pm; at other times very rare or no insect activity was recorded. To determine whether the flowers are autogamous or not, the inflorescence were bagged by nylon net bags before anthesis so as to exclude any insect visits. To determine whether the flowers are self-compatible or not, the pollinia of a flower was inserted into its own stigma with the help of a fine needle. However, a few inflorescences were left open as control to observe the results of natural/open pollination. Field photographs and videos were taken with the help of Nikon digital camera (COOLPIX P900; 16MP, 83× optical zoom). Repeated observations were made during the period of flowering, so as to note the visiting behaviour of insects and to identify the pollinators as well as the mechanism of pollination in the natural populations of *C. tricarinata*. One individual of the pollinator bee was also captured and killed in fumes of ethyl acetate for identification (Fig. 1D)

Observations and Results

Distribution

Calanthe tricarinata is found in India, Pakistan, Nepal, Bhutan, Korea, Malaysia, SouthEast Tibet, Thailand, Japan, and China, at elevations of 1,500-3,500 m amsl. In India, it is distributed in the Himalayan region from Jammu and Kashmir to Himachal Pradesh, Uttarakhand, Sikkim, West Bengal, Arunachal Pradesh, Meghalaya, and Nagaland (Chowdhery and Agrawala, 2013; Deva and Naithani, 1986; Hynniewta *et al.*, 2000; Singh *et al.*, 2019).

Flowering

April-July

Fruiting

August-September

Biological Status

Endangered (EN)

Description

Plants are terrestrial, upto 50 cm in height (Fig. 1A). *Pseudobulbs* broadly ovoid with distinct, concentric rings; *pseudostems* 8-22 cm long, sheathed. *Leaves* 2-4, elliptic-lanceolate to ovate-oblong, acuminate, petiolate. *Inflorescence* terminal, lax 5-14 flowered. *Floral bracts* half as long as the ovary, lanceolate, acute. *Flowers* showy, 2-3.5 cm across, green, edged with white; lip orange-red to brown with a yellowish green base, callus purple. *Sepals* similar, spreading, broadly lanceolate, acute-acuminate, 5-7

veined. *Petals* lanceolate, acute. *Lip* united to the whole length of the column, broadly 3-lobed, oblong, decurved, saccate at base; lateral lobes orbicular, spatulate, acute to sub-acute; apical lobe rounded to bifid, margins undulate; disc with a divided puberulous callus at base and 3-prominent, crenulate ridges (Chowdhery and Agrawala, 2013).

Habitat Ecology

Calanthe tricarinata usually grows in shady or semi shady, moist floor of tropical and sub-tropical forest. Sometimes, these are also found growing in open conditions. The species usually forms colonies of 5-15 plants. Presently, a good number of populations each comprising 5-10 plants were found growing on partially shaded loamy forest floors. Grasses, bryophytes, ferns, *Rosa* sp. and some of the tree elements including *Cedrus deodara*, *Pinus wallichiana*, *Rhododendron arboretum* etc. were found to be growing in its vicinity. Amongst orchids, *Cephalanthera longifolia*, *Goodyera repens*, and *Malaxis muscifera* were often found growing in its vicinity.

Pollination Biology

The flowers in the presently studied *C. tricarinata* were observed as self-compatible but mainly cross-pollinated. The result of the spur dissection suggested that *C. tricarinata* does not produce nectar since no nectar secretions were detected in the flower. In addition, no distinct odour could be detected with the nose during flowering of the species. The field observations revealed that the flowers were visited by a number of insects. The most frequent visitors were various species of bees. Western honey bee, *Apis mellifera* (Order: Hymenoptera; Family: Apidae) made the maximum visits to flowers; the bee visited the inflorescence in the zig-zag manner. The bee exhibited nectar seeking and pollinating behavior and shortly after landing on the labellum, it held the labellum with its fore and middle legs and inserted its proboscis deeply into the spur seemingly to suck the nectar inside (Fig. 1C). While probing, its head was pushed against the tip of the column, thereby receiving pollinaria (Fig. 1C). However, as there is no nectar in the flowers, the pollinator soon withdraws. After withdrawing, the insect visited another nearby flower and stayed for approximately 10 sec. After one to three repetitions, the insect would leave the patch of *C. tricarinata*. When the insect visited the next flower, the pollinia get attached from its head on to the stigma. After the pollinator failed to locate nectar from two to four flowers, they judged that there was no nectar and it flew to the next patch, indicating that this pollination mechanism might lead to out-crossing. During the present investigation, a single individual of pollinator

bee foraged only a few flowers, in a patch of *C. tricarinata*, in its single visit to the inflorescence, accounting for the low seed setting rate, in this species.

Discussion

There are no reports so far concerning the pollination of *Calanthe tricarinata*. It is an allogamous species, which means it relies on insects for pollination. Although, the flowers of *C. tricarinata* showed self-compatibility, but these are dependent upon the biotic agents for successful pollination. Presently, as the transfer of pollinarium, from anther to stigma, took place through the frontal surface of the head of the pollinator *i.e.* Western honey bee, *Apis mellifera* (Order: Hymenoptera; Family: Apidae), the mode of pollination is *Frontotribic*. Similar mode of pollination through the agency of bumble bees and carpenter bees has earlier been described in *Aerides odorata* (Chaturvedi, 2010) and in *Rhynchostylis retusa* (Buragohain *et al.*, 2015) as *Frontotribic*, as the pollinaria get attached on the fore-head.

While the pollination biology of *Calanthe* species remains largely unknown, seven species have been reported to be autogamous (Catling, 1990). It has been suggested that the analogous floral features shared with *Epidendrum* sp. indicate a role for lepidopteran pollination system (Dressler, 1993). One report from the Ryukyu Islands (Japan) has shown that a nymphalid butterfly, *Ideopsis similis*, is able to transfer pollinia between flowers of *Calanthe triplicata* on its proboscis (Sugiura and Miyana, 1996). Similarly, the cabbage white butterfly, *Pieris rapae*, has been confirmed as the pollinator of *C. argenteostriata* in SouthEast China (Zhang *et al.*, 2010). These findings indicate that a few *Calanthe* species bearing long spurs can be pollinated by butterflies or moths. However, there is also evidence that other *Calanthe* species might be pollinated by bees. For example, there have been reports that medium-to-large species of bees from the genera *Apis*, *Eucera*, and *Xylocopa* can carry the pollinia of *Calanthe* spp. (Ishihara, 1957; Ishikawa and Suzuki, 1992; Karasawa and Ishida, 1998). More recent studies have shown that, in temperate-subtropical regions, some *Calanthe* spp. with short spurs or no spurs are pollinated by large-bodied bees in the family Apidae [(*e.g.* *Apis*, *Bombus*, *Eucera*, and *Xylocopa*), Sakata *et al.*, 2014; Sugiura, 2013; Sugiura *et al.*, 1998; Suetsugu and Fukushima, 2014]. *Osmia cornifrons* (Megachilidae), *Apis cerana* ssp. *japonica*, and *Eucera nipponensis* are effective pollinators of *C. discolor* (Suetsugu and Fukushima, 2014). Pollination observations of *Calanthe striata* revealed that it was pollinated exclusively by the carpenter bee, *Xylocopa appendiculata circumvolans*

(Sugiura, 2013); in addition, interval photography showed that *Calanthe reflexa* was pollinated by two bumblebee species, *Bombus diversus diversus* and *B. hypocrita* (Sakata *et al.*, 2014).

During the present investigation, a single individual of pollinator bee foraged only a few flowers in its single visit to the inflorescence. The results suggested that *C. tricarinata* experiences a high degree of pollinator-limitation, but is also consistent with the trend for relatively low fruit set found in most orchid species (Neiland and Wilcock, 1998; Tremblay *et al.*, 2005). The dissection experiment produced no evidence of nectar secretion. The absence of floral rewards of any kind and combined with the nectar-seeking behaviour of the observed pollinator, indicate adoption of a generalized strategy of food deception system by the present species. Similar observations were made earlier in *Calanthe* species (Sakata *et al.*, 2014; Sugiura, 2013). Generalized food deceptive species often rely on pollination by native insects and/or insects whose food resources have become depleted (Internicola and Harder, 2012). Since pollinators often have a strong associative learning ability (Biernaskie *et al.*, 2009), it might be expected that generalized food-deceptive species may be avoided (Li *et al.*, 2011), with only a few non-rewarding flowers being visited before the pollinators switch to alternative species (Dafni and Ivri, 1981). The present data indicated that most pollinators only visited one flower per inflorescence thereby resulting in a low fruit set. This hypothesis was provided further support from the literature that this low pollinator visitation, could in turn reduce the reproductive success of deceptive orchids (Neiland and Wilcock, 1998; Tremblay *et al.*, 2005). Tremblay *et al.* (2005) noted that reproductive success (fruit set) in mimetic flowers was lower than in orchid species offering nectar. In particular, food-mimic species tended to show a lower conversion rate of flowers into fruits relative to sex-mimic (pseudocopulatory) flowers. However, although food mimicry pollination may be less efficient, it appears to dominate modes of pollination-by-deceit in some genera, *e.g.* *Cypripedium* (Bernhardt and Edens-Meier, 2010; Ren *et al.*, 2011) and *Thelymitra* (Edens-Meier and Bernhardt, 2014).

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