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Floral Visitors and Fruit Set in *Afgekia sericea* Craib (Fabaceae)

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ABSTRACT.–*Afgekia sericea* Craib (Fabaceae) is an endemic leguminous plant of Thailand. It is becoming rare due to fragmentation of its natural habitats which is probably leading to a reduction of reproductive success. This study investigated the interaction of the plant and its floral visitors in relation to fruit and seed set in three study sites which had different degrees of habitat disturbance. Sixteen bees, one small butterfly, one beetle and one sunbird were found to be visitors, but we found that only eleven bee species in the three genera, i.e. *Megachile*, *Nomia*, and *Pithitis* take part in the pollination. Some of these bees were particularly effective pollinators, especially *M. velutina* was found to be legitimate pollinator for *A. sericea*. The abundance of effective pollinating insects decreased markedly as the degree of habitat disturbance increased. These insect visitors are attracted by nectar guides on the vexillum and rewarded by pollen and/or nectar. Experiments in which flowers were enclosed in bags, thus preventing access by insects yielded no fruit set, while open pollination that allowed insects to visit flowers, resulted in fruit setting. These results indicate clearly that fruit set in this legume species depended largely on bee pollinators. However, percentage of fruit set was extremely low since less than 0.2% was observed from two natural sites.

KEY WORDS: *Afgekia sericea* Craib; visitors; pollinators; Papilionnoideae

INTRODUCTION

Many flowering plants depend on animals to disperse pollen for their pollination. This is a mutualistic relationship where each plant and the pollinator share their benefits. Animal-pollinated plants are rewarded their acting as pollinators in a variety of ways, such as nectar, pollen or edible flower parts. Direct attractants such as scents, bright color of floral parts advertised the flower to draw the pollinator's attention (Proctor et al., 1996). The problem of reproductive success such as flowering and fruit setting of wild and crop plants under natural habitat and field are usually related to drought, as has been point out by many workers, e.g. Fox et al. (1999) and Sari-Gorla et al. (1999). However, it is surprising that *Afgekia sericea* grown in Bangkok never produces a pod, despite producing plentiful complete flowers and having an ample supply of water. Furthermore, whereas plants grow in their natural habitat produce flowers mainly during the rainy season; plants raised in Bangkok

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produce flowers almost all year round (Boonkerd, 1992).

The genus *Afgekia* is a member of the bean family, Fabaceae. It has been a monotypic genus since the finding of *A. sericea* Craib based on a collection from Nakhon Ratchasima Province, N.E. Thailand (Craib, 1928). So far, it is also species that is endemic to Thailand. An additional endemic species, *A. mahidolae* Burtt & Chermsirivathana was found on the limestone hill in Kanchanaburi Province, western Thailand. Burtt and Chermsirivathana (1971) also noted that the two species are separated by the whole breadth of the Chao Phraya River. A third species, *A. filipes* (Dunn) R. Geesink was transferred from *Adinobotrys filipes* Dunn. It is distributed from south China to northern Thailand. So far, these three species of *Afgekia* have their own limited distribution in Thailand (Geesink, 1984).

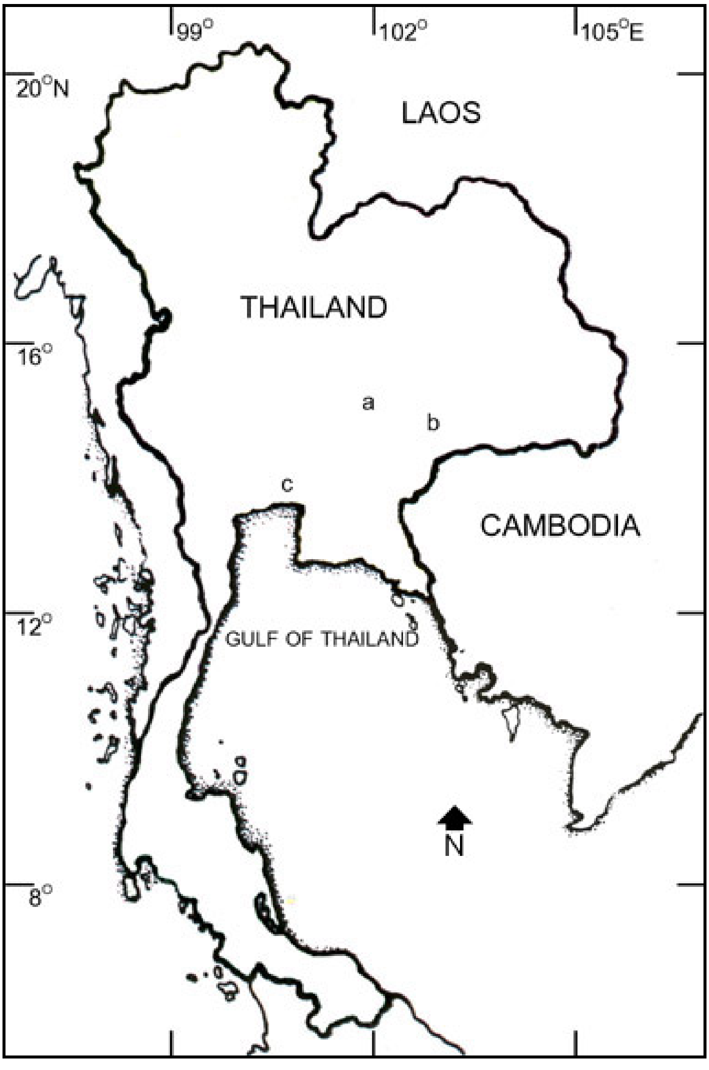

FIGURE 1. Map of Thailand showing the location of 3 study sites: a, Sakaerat Environmental Research Station (SERS), Nakhon Ratchasima Province; b, Phanom Rung Historical Park, Buri Ram Province; c, Department of Botany, Faculty of Science, Chulalongkorn University, Bangkok.

Afgekia sericea has become a rare species due to fragmentation of its natural habitats through removal of forest in order to meet increasing needs of land for agricultural purposes, housing and road construction (Boonkerd, 1992). So far, only one population is in the protected area of the Sakaerat Environmental Research Station in Nakhon Ratchasima Province (Fig. 1). No other known populations have legal protection. The other natural sites are remnants of the natural forest reserve and are endangered habitats of *A. sericea* at present. It is reasonable to assume that *A. sericea* growing in these locations will disappear soon due to the increasing forest destruction activities of the local agriculturists as well as its inability to produce germplasm.

It has long been observed by the authors that the amount of pod setting in *A. sericea* in its natural habitats is rather small as compared with the other plant species that belong to the same family or closely related genus, i.e. *Millettia*, despite its long inflorescence. As far as it is known, none or 1-2 mature pods per inflorescence can be observed at Sakaerat Environmental Research Station, and in some other sites in Nakhon Ratchasima Province. Total absence of pod production has been observed at some sites, especially on plant growing by the roadside along highway 201, starting from Si Keaw to Dan Kun Tod in Nakhon Ratchasima Province. The failure of fruit setting may be due at least in part to the lack of pollinators (Boonkerd, 1992). However, the possession of a papilionaceous type of flower suggests that *A. sericea* is may be a self-pollinating plant (Boonkerd, 1992; Douglas, 1997; Snow et al., 1996).

The initial interest in studies of *A. sericea* developed from the observation that this species has an unusually restricted geographical distribution. It therefore seems likely that there are some intrinsic physiological, ecological or morphological characteristics, that influence the adaptation performances of this species. Despite *A. sericea* being one of the most spectacular legumes, previously known as ornamental as well as medicinal plant almost nothing is known about its pollination biology. Knowledge of the pollination biology of this plant is really needed to improve our understanding of its implications for evolutionary process of reproductive isolation and therefore also for speciation as well as developing a conservation program for this endemic and rare species.

A preliminary study showed the presence of plant visitors and revealed a relationship with probable pollinators. With this information we were interested in investigating the animal involvement in the life of *A. sericea*. Accordingly, behavioral features of the visitors and their plant interaction studies were observed in two kinds of natural habitats and in the plants raised in Bangkok, all of which have different degrees of disturbance. Reproductive success of this plant in relation to pollinators was also investigated in terms of inflorescence, infructescence, pod, and seed productions.

MATERIALS AND METHODS

Plant materials

Afgekia sericea Craib is a woody perennial climber which grows naturally at or near the margin of the dry dipterocarp forest at low and medium altitudes and it is apparently confined to the Korat Plateau of N.E. Thailand. Flowering period normally starts from mid May to the end of October. The plant is characterized by having papilionoid flowers on many long racemose inflorescences, bearing a large number of flowers, up to 400 florets (Boonkerd, 1992). The calyx and corolla are covered by white, pubescent hairs. The calyx varies in color from creamy white to pale purple, united at base with 5 unequal teeth. The corolla is composed of 5 petals in papilionaceous form, i.e. one upper most petal, the “standard” or the “vexillum”, the two lateral petals, the “wings”; and the two lower most petals, the “keel”. The standard is greenish yellow with a pair of pink-purple nectar guides. The keel always, more or less united, form a robust, boat-shape like structure, which enclose the androecium and the gynoecium. The wings are usually in some way laterally connected with the keels. The pseudomonadelphous androecium is composed of 10 stamens. The gynoecium is composed of one simple pistil and is embraced by united stamen filaments. The placentation is marginal with usually 1-2, rarely 3 ovules. The nectary between stamen and pistil is the last part to develop after all the structures in the four whorls are established. It is an outgrowth of a receptacle in a thin collar of about 3 mm in height and enclosed in the base of the ovary. The flower produces nectar from nectary glands at gynoecium base. Each flower is open for only one day (unpublished data). The first series of mature fruits can be seen by the end of October, but in rather small quantity. More fruits are found during March and April (Boonkerd, 1992).

The study sites

Observations were carried out during 2001-2002 at Sakaerat Environmental Research Station (SERS), Wang Nam Khiao District, Nakhon Ratchasima Province at 270 m elevation in a lowland dry dipterocarp forest. This site is the only natural site of *A. sericea* that has been protected. Fieldwork was also carried out at Phanom Rung Historical Park, Chaloem Phra Kiat District, Buri Ram Province at 230 m elevation. This historical park is partly disturbed where a small natural population of *A. sericea* can be observed along both sides of a road which cuts through the park. Data and plant specimens were also collected from plants growing at the Department of Botany, Faculty of Science, Chulalongkorn University, Bangkok, at 2 m elevation (Fig. 1). They were grown from seeds originally collected from one wild plant at Sakaerat Environmental Research Station.

Floral visitors and their interaction

The fixed sample method as was described in Dafni (1992) was used in these studies during the growing season of *A. sericea*. The observations were made at three study sites which have different degrees of disturbance. Initially, observations on floral visitors were made both during day-time and night-time. Due to the apparent lack of floral visitors during the night and the fact that flowers almost invariably opened only during daytime, later observations were restricted to the period between the onset of flowering, which started at about 08:00 hour, and the end of flower visits by diurnal visitors about 17:00 hour. The visitation rate of pollinators was observed on two sunny days at Sakaerat Environmental Research Station. A total 120 hours of observations were made during the growing season of *A. sericea* in 2001 and 2002.

When flower visitors made contact with stigmas and anthers, those visitors were considered as pollinators. Their foraging behavior and their effects on fruit set were studied. Sample animals were identified and pollen on their bodies was collected. All insect specimens are kept at the Natural History Museum, Chulalongkorn University, Bangkok, Thailand.

Fruit setting

Fruit setting was observed from two natural sites, which were the same sites as in the observation of floral visitors. Thirty plants from each site were marked. The number of inflorescences, infructescences, pods, and seeds were recorded. Previous studies have shown the average number of florets per inflorescence to be 228.93 (unpublished data). The percentage of fruit set was calculated using this number. Fruit set from plants growing at the Department of Botany, Faculty of Science, Chulalongkorn University was also observed.

A pollinator-exclusion experiment (Kearns and Inouye, 1993) was conducted at SERS to determine whether or not pollinators were necessary for fruit production. Thirty reproductive plants with more than ten inflorescences were randomly selected in early August 2001 from near the center of the SERS population. On each plant, two inflorescences with all flowers still in bud were randomly selected. One was covered with a fine-mesh nylon bag with a mesh of about 1 mm to exclude pollinators and the second served as an open-pollinated control. Controls were not manipulated while in bud or flower. After fruits were initiated, controls were covered with the same material as the bagged inflorescences to capture pods as they dispersed from the rachis. We did not do hand pollinate a bagged sample, because our preliminary study showed that cross- and self- flowers can not produce any fruit.

RESULTS

Floral visitors

Nineteen animal species were found to be visitors of *A. sericea* (Table 1) at the three study sites. The majority of them are bees of the order Hymenoptera. The remainder are beetles of the genus *Mylabris* (*M. phalerata*), a butterfly of the genus *Chilades* (*C. pandava*) and the sunbird (*Nectarinia sperata*).

Among these Hymenoptera, the leaf-cutter

TABLE 1. Animal taxa observed visiting *Afgekia sericea* at 3 study sites: a = Sakaerat Environmental Research Station, Nakhon Ratchasima Province; b = Phanom Rung Historical Park, Buri Ram Province; c = Department of Botany, Chulalongkorn University, Bangkok (Reward: P = Pollen, N = Nectar).

Animal taxa	**Reward**	**Type of visitor**
Megachilidae		
Megachile velutina [abc]	P, N	Pollinator
M. monticola [ab]	P, N	Pollinator
M. conjuncta [a]	P, N	Pollinator
M. disjuncta [a]	P, N, Leaf	Pollinator
M. umbripennis [a]	P, N	Pollinator
M. sp. 1 [a]	P, N	Pollinator
M. sp. 2 [a]	P, N	Pollinator
M. sp. 3 [b]	P, N	Pollinator
Halictidae		
Nomia elliotii [b]	P	Pollinator
Nomia sp. 1 [b]	P	Pollinator
Podaliriidae		
Anthophora zonata [ab]	N	Non-Pollinator
Anthophora crocea [ab]	N	Non-Pollinator
Xylocopidae		
Xylocopa aestuans [abc]	N	Non-Pollinator
Xylocopa dissimilis [a]	N	Non-Pollinator
Anthophoridae		
Pithitis smaragdula [ab]	P, N	Pollinator
Apidea		
Trigona sp. [ac]	P	Non-Pollinator
Lycaenidae		
Chilades pandava [a]	N	Non-Pollinator
Meloidae		
Mylabris phalerata [a]	Petal	Floral herbivor
Nectariniidae		
Nectarinia sperata [a]	N	Non-Pollinator

bee genus (*Megachile* spp.) is the largest group, comprising 5 known species, i.e. *M. conjuncta, M. disjuncta, M. monticola, M. umbripennis* and *M. velutina,* and 3 unknown species. The others are two genera of mining bees, the genus *Nomia* (*N. elliotii* and *N.* sp.), and the genus *Anthophora* (*A. crocea* and *A. zonata*), two species of carpenter bee (*Xylocopa aestuans* and *X. dissimilis*), one species of dwarf carpenter bee (*Pithitis smaragdula*) and an unidentified stingless bee (*Trigona* sp.).

Among the three study sites, Sakaerat Environmental Research Station, Nakhon Ratchasima Province had 16 floral visitor species while 8 floral visitor species were observed at Phanom Rung Historical Park, Buri Ram Province. In contrast, the man-made habitat at the Department of Botany, Chulalongkorn University, Bangkok had only 3 species (Table 1).

Animal-plant interaction studies

The 19 floral visitor species can be categorized into pollinator and non-pollinator, according to analysis of observations of their behavior as to whether or not they may or may not take part in the pollination of *A. sericea* Craib. All species of *Megachile*, *Nomia* and *Pithitis* are considered legitimate pollinators due to their pollen loads and their opportunities to contact stigma. The others are non-pollinators, as shown in Table 1. Of the 8 non-pollinators, *Mylabris phalerata* is a floral herbivore, while the remainders are solely nectar and pollen robbers which could not facilitate pollination. The following are observed foraging behavior of the floral visitors.

Pollinator behavior

Megachile

Megachile velutina and *M. monticola* were abundantly found in the natural study sites. However, the first species seems to be more common as it has been found in all three study sites but the last was not found at the Botany Department. *M. conjuncta* and *M. disjuncta* were rare and found at both Sakaerat Environmental Research Station and Phanom Rung Historical Park.

According to this investigation, *Megachile* species spent approximately 10-15 seconds to cut and collect each leaf disc. As a pollinator, they visited each flower of *A. sericea* for 60 to 120 seconds to collect nectar and pollen. The visiting bee normally lands and clings to the wings of the flower. It then inserts its proboscis into the path between the vexillum and the upper edges of the keel, sliding it down to reach the nectar at the base of the staminal tube. While it sucks the nectar, its lower body part presses against the wings and the keel. The keel is then moved downwards so that the pistil and stamens somehow become exposed at the tip of the keel. The stigma and anthers then come into contact with the underside of the bee's body. The bee rakes pollen from the anther and stuffs it among dense rows of long stiff hairs (scopa) on the underside of the abdomen until it is entirely packed with pollen. At the same time, the bee rubs its belly across anthers and stigma. Finally, the pollination is successful. As the bee leaves the flower, the wings and keel spring back to its initial position. The exposed stamens and stigma are then again covered.

Pollen grains deposited on *Megachile*'s body matched well with pollens of *A. sericea* in all morphological characters. Compared with other *Megachile* species, *M. velutina* seems to be the earliest bee to arrive at the flower, except for an occasional *Mylabris phalerata*. It is often found abundantly at approximately 10:00 hour and again at 14:00 hour (Fig. 2), especially on sunny days. It is also restless and rather timid. It may nevertheless be the most efficient pollinator because of its relatively high rate of re-visiting and consistency to the flower of *A. sericea*.

Megachile monticola is the second most common pollinator. However, it is less restless and may less daring in collecting pollen of *A. sericea* than *M. velutina* since it has low frequency of re-visitation. Though *M. conjuncta*, *M. disjuncta* and *M. umbripennis*

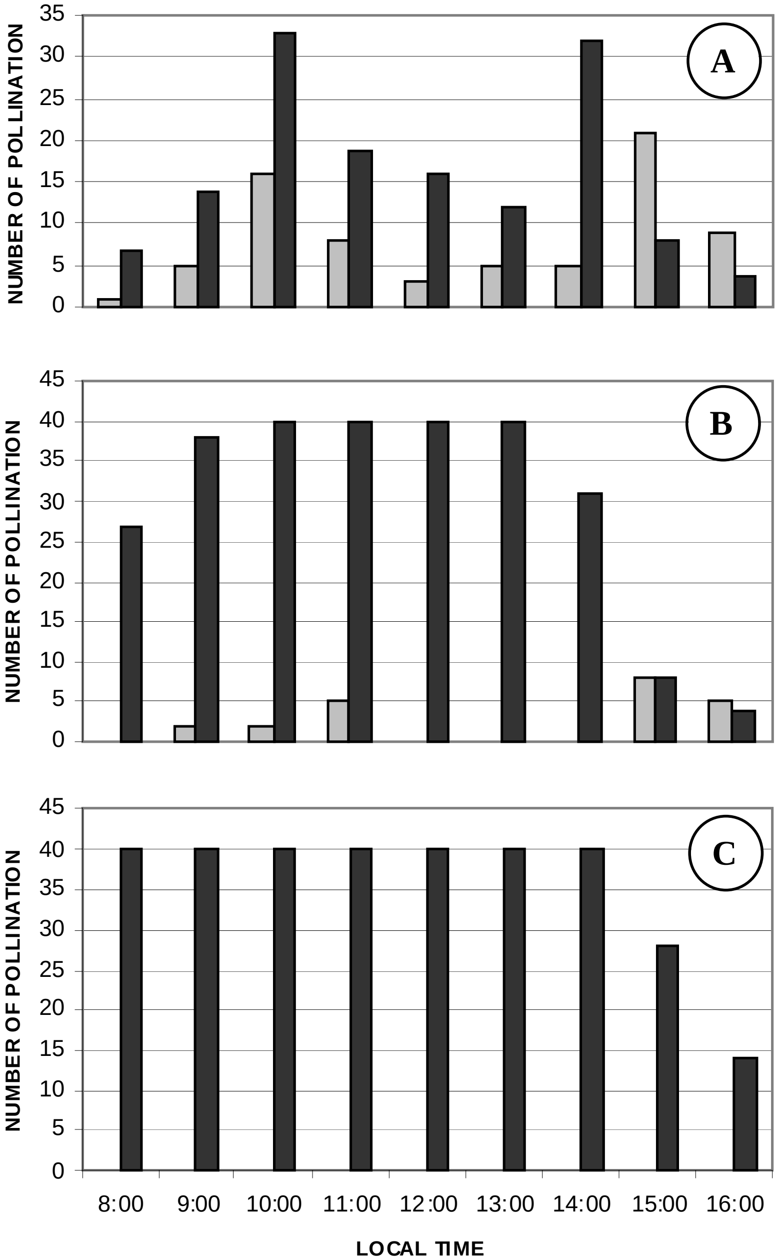

FIGURE 2. Frequency of principal pollinators in *Afgekia sericea* Craib on two sunny days. For convenience in illustration, pollinator visiting frequencies of more than 40/hour are shown as 40. a: *Megachile velutina*; b: *Nomia elliotii*; c: *Pithitis smaragdula*; ■ : August 2002; ■ : September 2002.

had been found to carry pollen of *A. sericea* and have similar pattern of foraging behavior to *M. velutina* and *M. monticola*, their appearance was so rare. According to the present observations, we recorded them only 8, 5 and 1 times, respectively during 2 years.

Nomia

Nomia elliotii was found in abundance at Sakaerat Environmental Research Station and also found at Phanom Rung Historical Park, and an unidentified *Nomia* species was found only once at Phanom Rung Historical Park.

The foraging behavior indicates that *Nomia* seems to be interested only in collecting pollen as it has never touched or gone towards the base of the vexillum, where the nectar can be reached. It lands directly on the wing and presses its head towards the tip of the wings or crawls underneath the hood of the wings to open them up and then forcibly presses its head down into the keel to seek and collect pollens. It collected pollens in the pollen baskets or corbicular on hind legs like honey bee. *Nomia* has its daily emergence peak between 11:00-13:00 hours (Fig. 2).

Pithitis

Pithitis smaragdula is the only species of *Pithitis* found in this present investigation. It can be easily recognized by its small-sized and brilliant metallic green body. This potential pollinator was found in the two natural study sites, i.e. Sakaerat Environmental Research Station and Phanom Rung Historical Park.

Like *Megachile*, *P. smaragdula* collected both nectar and pollen but in a different pattern of visitation. When this bee tracked for the nectar, it landed on the wings and moved directly to the base of the vexillum. Contrary to the *Megachile*, when it sucked the nectar, its head pointed outwards to the tip of the wings and keel, then its lower body part pressed against the vexillum, not the wings or keel. On the other hand, it opened the wings and forcibly entered into the keel to collect pollen grains. It kept pollen in the pollen baskets or corbicular on its hind legs like the honeybee.

Non-pollinator behavior

Xylocopa

The carpenter bees searched only for nectar from *A. sericea*. These bees can be found at all hours of daytime. Instead of landing and facing directly on the wings, the carpenter bees always cling to the side of the wings and keel and penetrate their proboscis down to reach the nectar deposit underneath the base of the vexillum. In some cases, they flew and landed on the abaxial side of the vexillum of the flower, which situated in the lower position in the raceme (or the flower that opened in the previous day) and sucked the nectar from the newly opened flower. They never touch directly on the tips of the keel and wings.

Trigona

The stingless bee (*Trigona* sp.) we observed measures only 3-4 mm in size. In this species, pollen loads are always found on corbiculae. Stingless bees visit flowers of *A. sericea* in groups during all daytime hours. They spent 1-6 minutes per flower. According to their behavior, they clung to the wings and keel and just moved around but could not open them. This may be because these bees are rather clumsy, often loosing their grip and falling off from flowers. They collected only pollen grains on parts of the flowers, which left were over by other visitors. They may also collect pollen directly from anthers but only from flowers where the keel was bit open by other insects. They collected pollen grains by combined working of the forelegs and mouthparts. Pollen grains are then passed from the forelegs to the mid legs and then to the hind legs where they are gathered inside the pollen basket. This species of bee almost never contacted the stigma of the flowers, so it should not be considered a pollinator of *A. sericea.*

Anthopora

Anthophora zonata is smaller than *Trigona* sp. *A. crocea* has deeper black body and wings than *A. zonata*. Both are similar in color band but *A. crocea* has more abundance black hair on thorax and legs. *A. zonata* was more commonly found than *A. crocea*. It was found at Sakaerat Environmental Research Station and Phanom Rung Historical Park.

Anthophora spp. collected only nectar from the flowers of *A. sericea*. Even though their foraging behavior is more or less similar to that of *Megachile*, the keel was never pressed downwards to uncover the stigma and anthers during their visits. Moreover, they often suck the nectar from the lateral side of the flower by clinging to the vexillum rather than to the wings. This genus can be found from around 10:00-15:00 hours on sunny days.

Mylabris

The oil beetle, *M. phalerata* is a large beetle. It has a long and broad body (ca. 25 x 9 mm), black wings cases with three broad, wavy, orange to yellow bands. It also has a unique disagreeable odor. It has been found to be the only pest of *A. sericea* in this present study and found just only at Sakaerat Environmental Research Station.

From the present investigation, it seems likely that the oil beetles fed on the flower parts. They normally bit and cut the wings, keel, anther and may eat pollen grains as well. Many pollen grains can be found sticking on hairs on their heads and bodies. This beetle species always found in the morning.

Chilades

In the present study, *Chilades pandava* is the only butterfly species which visits *A. sericea* and is found only at Sakaerat Environmental Research Station. It is a small butterfly measuring only about 15 mm in size. *C. pandava* has brown wings, with black spots on the hind wings.

Chilades pandava collected only nectar from the flowers. They landed on the wing and moved directly towards the nectar guide and inserted their proboscis down into the path at the base of the vexillum and sucked the nectar. Like *Anthophora*, they never caused the stamen and pistil to be exposed from the keel. Thus, no part of anthers or stigma can touch their bodies.

Nectarinia

Nectarinia sperata or purple-throated sunbird was found only at Sakaerat Environmental Research Station. This sunbird is usually found in rainy days, in the morning or in the evening. They perched on the rachis of the inflorescence and projected their beaks directly to the base of the vexillum and sucked the nectar without any contact with the wings and keel.

Fruit set

Afgekia sericea produced fruits and seeds only at its natural sites, but there were significant site effects on inflorescence, infructescence, pod and seed production and percentage fruit set in 2001 (Table 2). However, percentage fruit set at those two sites was extremely low, since only 0.12 and 0.17% were observed at Sakaerat Environmental Research Station and Phanom Rung Historical Park, respectively.

No fruit set was observed when floral visitors were excluded from inflorescences at Sakaerat Environmental Research Station, while the open-pollinated control produced some fruits during the third and the seventh week of fruit development.

TABLE 2. Reproductive success in *Afgekia cericea* at two study sites

Reproductive success	Sakaerat Environmental Research Station (mean±SE)	Phanom Rung Historic Park (mean±SE)
Inflorescences (number)	9.7 ±1.43	14±1.06
Infructescences (number)	2.36± 0.35	3.92±0.25
Pods (number)	2.76± 0.44	5.28 ±0.31
Seeds (number)	5.5± 0.87	10.5± 0.6
%Fruit set	0.12± 0.17	0.17 ±0.08

DISCUSSION

It was found from this study that insects are the main floral visitors of *A. sericea*. Basically, the conspicuous vexillum functions as a visual attractant or the main optical display organ and is thus frontally exposed and possesses a nectar guide of colors, that is, it is decorated with a pattern of colours that may guide visiting animals to the deposits of nectar. These characters may help either make the plant more distinguishable or make the right landing platform for insects or bees. In *A. sericea*, the nectar guide is pink-purple which may be in part attracted the insect pollinators. In contrast, nectar guides are absent in bird-pollinated taxa (Kay, 1987). Like the other species of the Fabaceae, the keel and the wings of *A. sericea* serve as a landing platform for visiting insects, which are predominantly Hymenoptera (Weberling, 1992; Endress, 1994).

In *A. sericea*, a structure called the pseudomonadelphous androecium, with two apertures formed at the base of the staminal tube, was observed. A nectary was also found between the filaments and the carpel base (unpublished data). This type of filament tube development as well as the presence of the nectary indicates that *A. sericea* is adapted to insect-pollination, especially by bees. Typically bee-pollinated flowers have a delicate sweet fragrance (Weberling, 1992). However, this is not in the case with *A. sericea*.

Floral visitor and animal-plant interaction

From these observations we recorded that *A. sericea* has about twenty species of floral visitors. Some of them are classified as its pollinators due to their foraging behaviors that lead some contacts between anthers and stigma or transferring of pollen from anthers to stigma in one way or another. The Leaf-cutter bees, *Megachile* spp., seem to be the most important pollinators, especially *M. velutina*. Due to their occurrences in all study sites. *M. monticola* may be also an important pollinator but it has rather low frequency of re-visitation. The remainder tend to be pollinators according to their behavior, but are clearly less important, at least in the present study, since their appearances was distinctly rare. In addition, *Megachile* spp. has been reported elsewhere as efficient pollinators of plants with papilionaceous flowers (McGuire, 1993; Momose et al., 1998).

The behavior of *Nomia* spp. together with *P. smaragdula* suggests their potential to be effective pollinators too, but they are not commonly found like *M. velutina*. However, *Nomia* are excellent pollinators for several other species, as well as pea (Proctor et al., 1996; Free, 1970). *P. smaragdula* sometimes behaves like a nectar robber as it sucks the nectar from the flower but takes no part in pollination. The results from this study support the findings of many workers that bees are the predominant pollinators of the legume, especially the Fabaceae (e.g. Arroyo, 1981; Momose et al., 1998; Galloni and Cristofolini, 2003; Liu and Koptur, 2003).

Non-pollinator

Many investigations have suggested that *Xylocopa* spp. is a common pollinator in some large-flowered species of the Fabaceae, such as *Centrosperma*, *Canavalia*, *Vigna* and *Harpalyce* (Arroyo, 1981; Endress, 1994; Momose et al., 1998; Mack and Milligan, 1998). In this study *Xylocopa* is found to be a common visitor in *A. sericea*, but it could not pollinate the flower. Although many floral characters of *A. sericea* are similar to Xylocopa-flowers, i.e. strong architecture, hidden nectar, unsaturated color, one-day flower and steady-state flowering strategy (Endress, 1994), however it seems likely that the pedicel of *A. sericea* is not strong enough to directly support the weight of such a large bee in comparison with the other fabaceous genera which are pollinated by *Xylocopa*. Thus, *Xylocopa* has never visited the flower of *A. sericea* directly on the wings and keel so it has less chance to touch the male and female parts of the flowers which are located at the tip of the keel.

After *Megachile*, *Nomia*, *Pithitis* and other visitors leave the flowers, there will be a small amount of pollen deposited on the surface of the petals. Stingless bees (*Trigona* sp.) and beetles have been found to collect those pollen grains but they did not touch the stigmas. The behavior of the oil beetle species (*M. phalerata*) is quite interesting. Since this beetle always bites floral parts, the pollinating stigma may be lost through their behavior. One might suggest that the low percentage of fruit setting at Sakaerat Environmental Research Station may be partly due to the damaged stigmas which lead to unsuccessful pollen germination. However, the percentage of flowers that were damaged by the activity of oil beetles was very low (less than 1%), thus the main reason of low fruit set ought not to be attributed to these beetles.

The appearance of the purple throated sunbird (*Nectarinia sperata*) as a flower visitor of *A. sericea* is not surprising. Even though the majority of bird-flowers often has a relatively long and tubular parts with protruding stamens and stigmas (Endress, 1994), the basic structure of bird-pollinated plant can be diverse since a wide range of plant families is involved in bird-pollination. For example, 23 species of *Erythrina,* 3 species of *Mucuna*, and 4 species of *Sophora*, (Fabaceae) are found to be pollinated by hummingbirds, sunbirds and the other birds (Arroyo, 1981; Proctor et al., 1996; Bruneau, 1997). However, it is quite clear in *A. sericea* that this sunbird has no role in pollination since they just come for the nectar only and their appearance was observed only on rainy days. These facts may suggest that this sunbird is not actually attracted by the flower of *A. sericea* in normal situations.

Sixteen out of nineteen floral visitors were found at a natural undisturbed habitat in the Sakaerat Environmental Research Station, of these 8 species are potential pollinators. Rather similarly, 9 species of floral visitors were observed at Phanom Rung Historical Park, of these 6 species are potential pollinators. This natural site was partially disturbed due to road construction through the park. In contrast, floral visitors in the man-made habitat at the Department of Botany, Faculty of Science, Chulalongkorn University, Bangkok seem scarce, since only 3 bee species were observed, and only one species was a potential pollinator, i.e. *M. velutina*. These pollinator data indicate that the complete failure of *A. sericea* to produce fruit in urban habitats like Bangkok is caused by severely reduced pollinator presence. This finding indicates that the reduction in pollinator diversity tends to be a strong response to disturbance of natural forest habitats. These pollinators, without doubt, require natural, undisturbed forest, for optimum abundance and activity. Corresponding results were presented by Johnston (1991), Burd (1994) and Fischer and Matthies (1997).

Fruit setting

It was found that *A. sericea* successfully produced a number of inflorescences at all study sites. However, fruit and seed set were observed only at natural sites where there were a number of proper pollinators. The inflorescence, infructescence, pod and seed production are significantly higher at Phanom Rung Historical Park than at Sakaerat Environmental Research Station (Table 2) despite lower number of floral visitors being observed at Phanom Rung Historical Park (Table 1). It seems likely that the effective pollinators at the two natural sites are not different. However, the visitation rate of pollinators was not studied at Phanom Rung Historical Park so there is not enough pollinator data available to compare their activity at those two sites. Anyhow, the discrepancy in reproductive success of these two sites may be in part related to the amount of rainfall throughout the period of data collection. It was rather dry at Sakaerat Environmental Research Station in 2001 as compared with Phanom Rung Historical Park (Chourykaew, 2002). Experiments have shown that drought has a profound effect on reproductive success of both wild and cultivated plants (Fox et al., 1999; Sari-Gorla et al., 1999; Petit, 2001).

This study has shown that fruit set in *A. sericea* is extremely low as compared with the other legume species, especially in crop plants (Van der Maesen and Somaatmadja, 1992). Limitations to fruit and seed production in any single year are likely to lead to permanent reproductive failure in this taxon (Kaye, 1999). Excluding pollinators in our bagging experiments indicate clearly that fruit set in this legume species depended largely on bee pollinators. However, no fruit setting was observed at Chulalongkorn University despite the presence of *M. velutina*, a legitimate pollinator. From our experiments (unpublished data) we found that *A. sericea* has a self-incompatibility system, which prevents self-fertilization. It is a genetically controlled system which causes rejection of self-pollen (Dafni, 1992). In addition, self-incompatibility was frequently found in Papilionoideae (Arroyo, 1981) and seems to be the main factor controlling the breeding system throughout the family (Arroyo, 1981; Proctor, Yeo and Lack, 1996). Many members of this family do need to have bees as pollinators for their successful reproduction (Momose et al., 1998; Galloni and Cristofolini, 2003; Liu and Koptur, 2003).

CONCLUSION

At present, *A. sericea* has isolated populations of small size, due to habitat destruction and fragmentation. These populations face an increased risk of extinction due to fluctuations of environmental conditions, reproduction limited by poor pollinator success, and the erosion of genetic variability. These conclusions have also been drawn by other researchers (e.g. Menges, 1991; Schemske et al., 1994; Steffan-Dewenter and Tscharntke, 1999; Cunningham, 2000; Moody-Weis and Heywood, 2001; Goverde et al., 2002).

Available evidence suggests that an increasing level of inbreeding may occur in *A. sericea* in an adaptation to the scarcity of legitimate pollinators. Evidence in favour of this interpretation has now been produced by Fischer and Matthies (1997) in *Gentianella germanica* and Kaye (1999) in *Astragalus australis* var. *olympicus*.

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