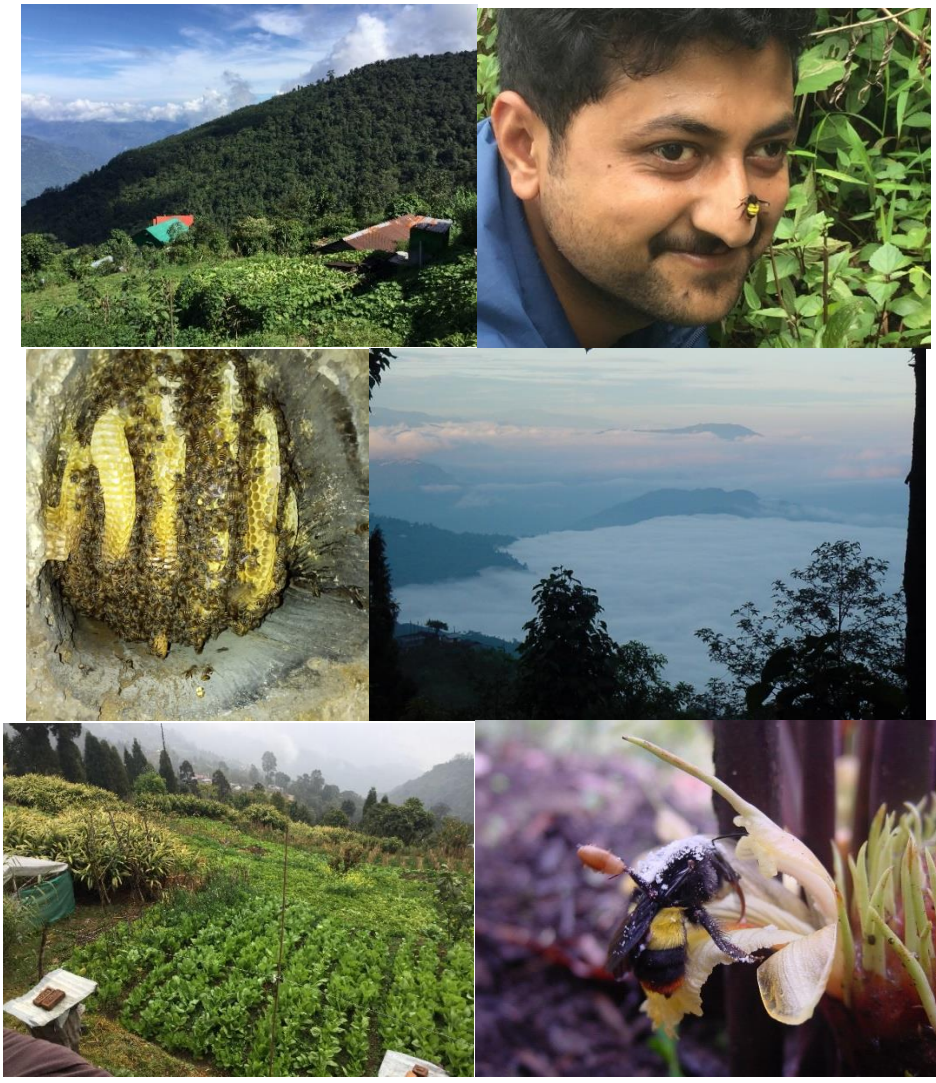
Himalayan Bee Watch and Bee Museum: A platform for documentation, monitoring, and research and a window for sustainable development of Forest Villages of Darjeeling



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Disclosure

This is a final technical report submitted to the funding body, NMHS. Most of the findings of this research are in different stages of the publication. I caution and request the readers to contact me directly at sinu@cukerala.ac.in before reusing the information given in the report and with proper acknowledgement.

A video excerpt of the research may be seen at https://youtu.be/4MLuOjcEqjE

Articles published from the research

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Project Title:	**Himalayan Bee Watch and Bee Museum: A platform for documentation, monitoring, and research and a window for sustainable development of Forest Villages of Darjeeling**
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Executive summary

Indian Himalayan Region is spotted by tiny to small villages and hamlets. Many of them are formed as forest villages and situated in the fringes or buffer area of protected forests and natural reserves. Agriculture and service to the forest department are the traditional sources of livelihood for the dwellers of these village. Very recently, these villages have been opened for sustainable eco-tourism activities. Although agriculture is a main source of income, knowledge of what pollinate what crop, and what is the status of pollinators in the IHR is still a major knowledge gap. Through this project, we aim to unearth the pollinator diversity, key pollinators of major cash and vegetable crops that the dwellers of the villages grow in their farms to form a basis for future research and management of pollinator resources. The major part of the research has been conducted in the Rampuria and Pubong forest villages. We involved the farmers to give awareness of the pollinators and the methods for conservation of pollinators. A pollinator demonstration plot with trained villagers has been established at Rampuria forest village for education and outreach activities. The forest villages of Darjeeling are served by only less than ten species of bees and several species of hoverflies. This is shocking as the farms have several field vegetable, cash, and ornamental crops. Among them, bumblebee – *Bombus haemorrhoidalis* has been evolved as the major pollinator of the forest villages. Apart from it, managed honey bees are the major sources of pollination service in crops. However, they are futile pollinators for some cash crops, such as large cardamom. Our interaction with the dwellers suggests that they were aware much of the bumblebees and honeybees, but they have no knowledge for what are the specific pollinators of what crops. Although the dwellings are decorated with several ornamental plants, the dwellers are unaware of whether they help in conserving pollinators. We have made specific recommendations for plants – ornamentals, native shrubs, and crops – for conserving pollinators of the Darjeeling part of the IHR.

Introduction

The forest villages and adjoining revenue villages are the hamlets seen in the extensive buffer zone of protected forests of North Bengal. In Darjeeling, a few of such villages and hamlets can be seen around the Senchal Wildlife sanctuary. This sanctuary has pristine evergreen forests at an elevational range of 2000 – 3000 m asl. At least five forest villages and three revenue villages are seen close to them. Majority of the old-generation dwellers find their livelihood through small-scale agriculture, diary, and service to the forest department in their developmental activities. A small number of the younger generation of the hamlets, though have migrated for work outstation, most of them have continued staying in the villages and involved in agricultural activities. All farmers of both the revenue and forest villages follow organic mode for agriculture. They cultivate these crops primarily for selling in local markets and their own consumption. Therefore, agriculture still forms a backbone of their economy, nutrition, and health. A knowledge of farmland biodiversity might help the farmers plan their land and

A traditional small-holding farm of a forest village in Darjeeling

A panoramic view of Rampuria forest village, pollinator demonstration plot of the project

The project objectives:

- To document bee genetic resources of Darjeeling Himalayas;
- To identify key pollinators of crop plants of Himalayan hamlets;
- To document wild foraging plants of the bees with special reference to the type of plants (native versus invasive) with an aim to use selected native plants as forbs plants to sustain pollinator populations in crop lands;
- To educate and give awareness on ecosystem services provided by the bees and citizen science program to monitor bee diversity of the Himalayas.

Methodology

Study site

The study was operated from the revenue and forest villages of Pubong, Tinchuly, Rambi, Rangpo, Maneydara, Davaipani, Takdah in Darjeeling parts of central Himalayas and in the villages of the hill tracts of Siliguri – Darjeeling highway. All these villages have natural forests of either protected areas (Senchal WLS) or unprotected reserves as their boundaries. Because our interests were to assess the pollinators and pollinator-friendly plants of the villages that may help agriculture of small-holder farmers, all our surveys were conducted from the village and agriculture premises. No attempts have been made to survey pollinators of protected areas.

Sampling methods

We adopted “flower watching” for scoring pollinators and pollinator-friendly plants. In that, we spent several hours with the flowers for direct watching of pollinator activities on the flowers. During the survey, the researcher sat near one or several flowers (depending on the crop species and inflorescence type) for a straight one hour and recorded a) the visitor species visited the flowers, b) the times each species visited to the flowers, c) the forage material (pollen, nectar, or both) the visitor collected. This data was used to calculate visitation rate of each pollinator species and the visitation rate of overall visitors. To calculate the visitation rate, the number of visits was divided by the number of flowers. The

visitation rate is therefore denoted by visits/flower. Flower-visiting insects were collected for determining the species using a stereo-zoom microscope (Zeiss). We surveyed almost every flowering plant in the villages, such as crop plants, wild herbaceous and shrubby plants, small trees, and ornamentals that flowered different months. We surveyed the selected plants for three years of flowering.

Among the crops the villagers grow in Darjeeling, large cardamom (Amomum subulatum) is a commercially important cash crop. It is sold in the market as black or large cardamom. It is a major backbone of the local villagers in Darjeeling and grow extensively as an agroforestry practice or even cultivated directly under the Sun. Sinu & Shivanna (2007) and Sinu et al. (2012) have studied the pollination biology of this crops in 2006 in some villages of Darjeeling and parts of Sikkim Himalayas. Since it is major cash crop for the villagers, we have done an extensive survey of its pollinators. We also were curious whether the pollinators or pollinator visitation rate differed between years. We made a detailed study on the number of opened flowers per day, flower progression across season, the proportion of pollinated flowers, and the proportion of flowers set into fruits.

Pollinator management and conservation require not only flower resources, but also their nesting resources and habitat. In order to understand the nesting resources of major pollinating bees, we made a random survey in the village premises.

Pollinators of crop plants

Large cardamom

Large cardamom flower is a specialist one having bilabiate zygomorphic large showy flower borne on ground inflorescences. It is one of the most resourceful flower with copious amount of nectar and pollen grains for the floral visitors. According to Sinu and Shivanna (2007) and Sinu et al. (2012), Bombus haemorrhoidalis and managed honey bees of Apis cerana are the dominant and in high altitudes the only bees interacting with the flowers.

During the study period, it flowered during late March to mid-August in the hills of Darjeeling. In the low altitudes (600 – 900 m asl), it flowers early (mid of March) and completes flowering by the end of June. In the high altitudes (above 1000 – 3000 m asl) the flowering commenced late by late April, which goes till the mid of August. It opens early morning by around 4 AM in the hills and starts senescing from 5 PM the same day.

It is one of the first resourceful plants to offer resources for the bees that break winter dormancy in the region. We approached pollination studies in large cardamom by asking hitherto unstudied basic aspects, such as:

1) how many flowers a plant produce in one flowering season,
2) how many of the opened flowers set fruits, and
3) what is the impact of pollinator diversity and pollinator visitation rate on pollination efficiency in large cardamom.

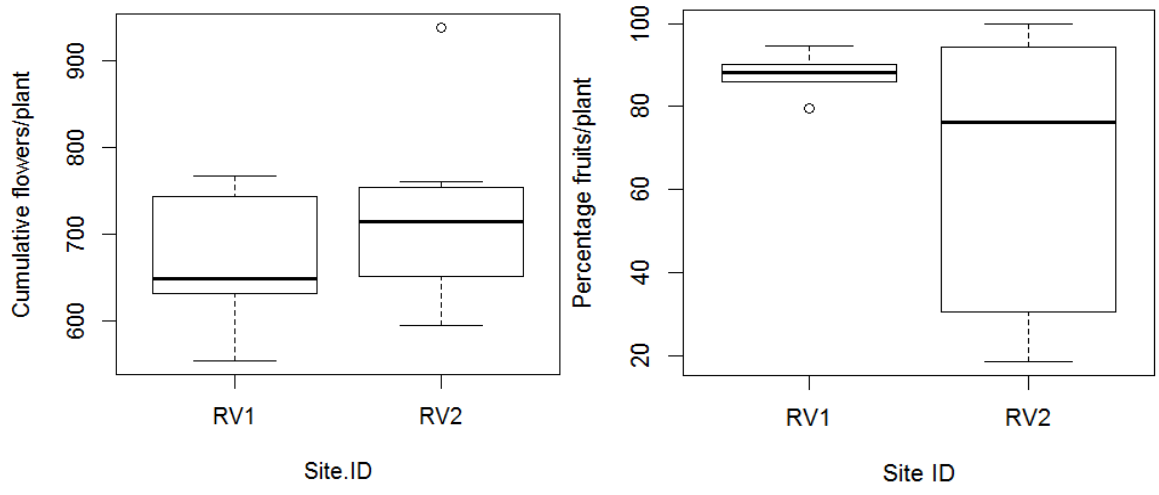
The plants and clumps of large cardamom in Darjeeling

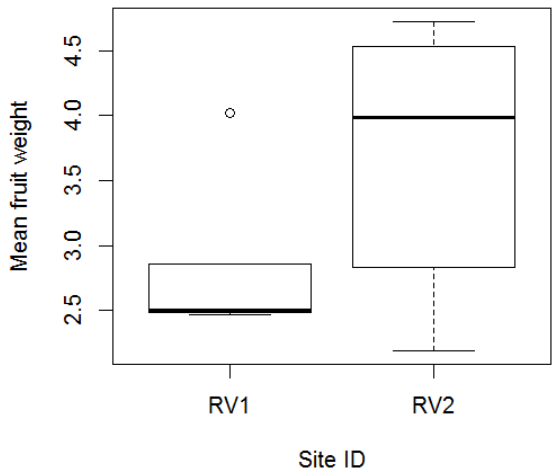
A closer look of a clump of large cardamom. Each longer horn you see in the inflorescence is a future flower

A closer look of a large cardamom flower

Flower progression and natural fruit set in large cardamom

In order to understand how many flowers a large cardamom plant produces and how many of them set fruits, we monitored 20 2-year-old plants in two sites in Darjeeling at about 2000 m asl for the entire flowering season (May – August). We went to each plant and counted the number of flowers opened each day. This gave us the data of cumulative numbers of flowers opened per plant in the whole flowering season. The cumulative numbers of flowers per plant varied between 553 and 767 in RV1 and 594 and 939 in RV2. We monitored fruit set in these plants and harvested the fruits.





A total of 6713 flowers and 7138 flowers were counted respectively in the plants of RV1 and RV2. The mean number of flowers opened per plant (N=10 for each village) in village 1 (RV 1, 671.3±70.31 SD) and village 2 (RV2=713.8±99.8) did not differ (t=-1.1, p=0.23). However, the percentage of fruits developed per plant (87.8% vs. 64.88%) varied significantly between the villages (t=2.21, p=0.05). Although the fruit set was higher in village 1 than village 2, the fruit weight was similar for both the sites (t=-1.95, p=0.07).

Although many factors might predict pollination success in plants that include soil nutrients, soil microbes, plant health, pollinators, pollination success and so on, we postulate that pollination could be a major driver of the difference in fruit set of these two sites. In the village 1(RV1), bumblebee visitation rate to the flowers was much higher than the village 2 (RV2). The visitation frequency of bumblebee in Rajen plot (RV1) was 0.37/ flower per fifteen minutes; in Sunil plot (RV2), it was 0.06/flower per fifteen minutes (t=3.65, P=0.0008). Interestingly, flowers of RV2 (0.16 visits/flower/15 min.) were visited more by honey bees than RV 1 (0 visits) (t=-2.6, P=0.01). Honey bees seemed to be the poor pollinators of large cardamom.

Pollinators and pollination efficiency

Large cardamom though dominates the farms of Darjeeling Forest and revenue villages and resourceful, but only very few species of bees have evolved traits to interact with the flowers. Among them, wild bumblebee, *Bombus haemorrhoidalis* was the predominant one. They are social bees and have burrowing nest. Before winter sets, they mate and queens make new burrows and lay eggs. The juveniles overwinter in the nest and emerge from March onwards. Large cardamom makes a resourceful plant for the emerging bees. The queen forage most during the initial phase of nesting. Therefore, large cardamom flowers receive visits of queen bumblebee bees for the first month of flowering. During the progression of flowering, workers and even drones dominate the visits to the flowers. In farms that have honey bees maintained in bee boxes, honey bees too visit the flowers of large cardamom. In fact, in such places, they outnumber the visits of wild bumblebees due to their high abundance in colonies. Interestingly, *Apis cerana* is identified as a pollen robber – a visitor that forage pollen grains, but do not transfer pollen grains to the stigma. Therefore, they are of no use to large cardamom pollination.

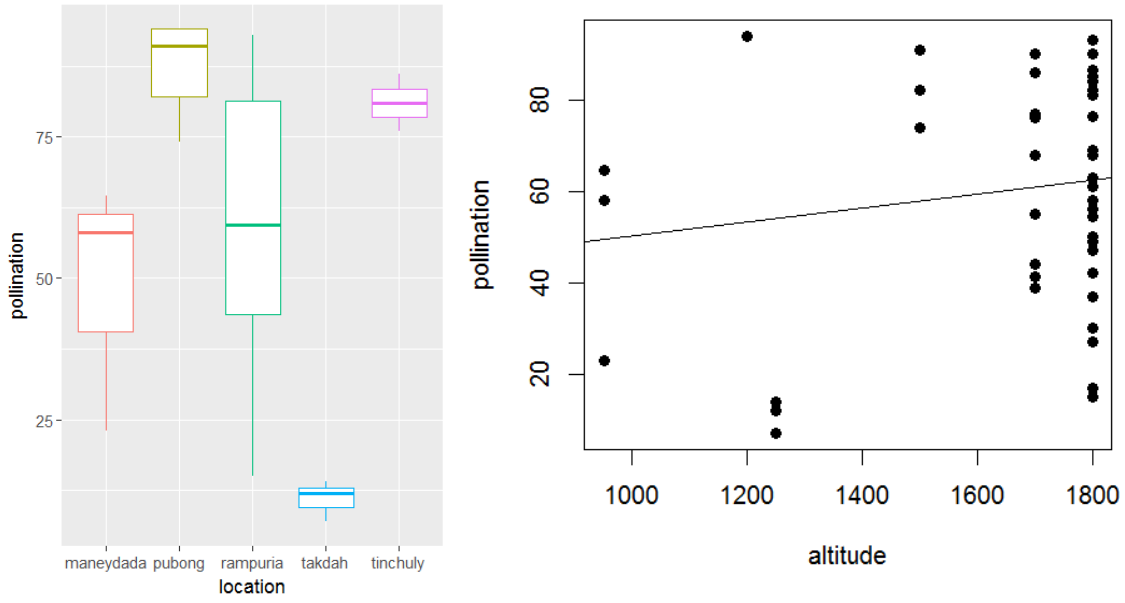
In the present study, we examined over 8000 flowers of large cardamom from 21 sites in Darjeeling to examine open pollination efficiency. For analyses, the sites were grouped into major locations. Percentage of flowers pollinated as evidenced by the pollen grains in the

stigma of flowers was used in the analyses. All the flowers were plucked / examined afternoon during the senescence period of the flowers.

A large cardamom flower showing its various parts. It has a 2.3 cm long corolla tube (Left). The anther-stigma column of a large cardamom flower shows the arrangement of longitudinally split anthers and the stigma opening outward (right)

The style of a large cardamom flower with the stigma opening outward (left); the anther of large cardamom flowers shows the abundance of white powdery pollen grains – a major resource for the pollinating bees

Pollination efficiency (percentage of pollinated flowers) differed significantly between five major locations ($F=7.13$, $p=0.0001$). In two sites, pollination efficiency in plants differed quite a lot. In three sites, proportion of pollinated flowers in randomly selected plants were similar. This suggests that pollination efficiency in plants might be varied due to the availability of efficient local pollinators. It may be reiterated here that many villagers have maintained honey bee colonies in the vicinity of large cardamom fields in the pretext that they can bring about pollination in the crop. Our results are that the proportion of honey bee visits in the overall pollinator visits can reduce the pollination efficiency in the crop. The crop pollination did not differ across altitudinal range ($R^2=0.02$, $F=1.06$, $p=0.3$), suggesting that altitude is not a driver of pollination in large cardamom.



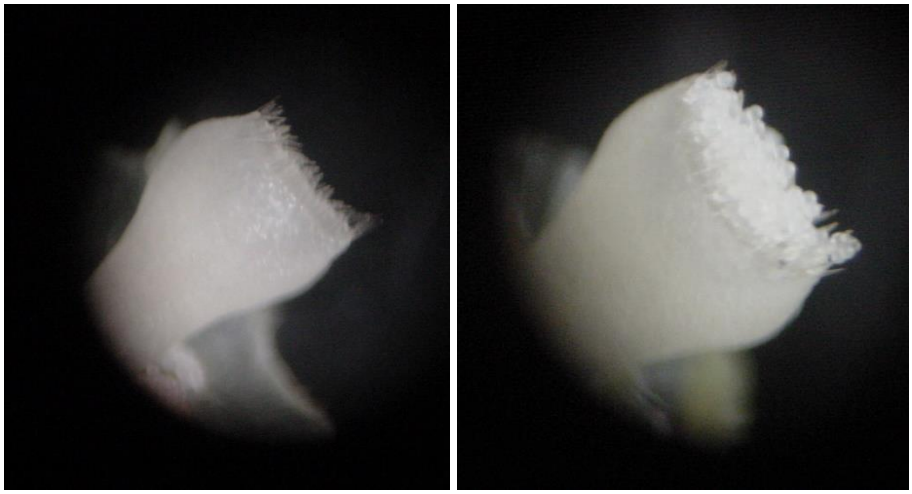
Pollination efficiency in large cardamom flowers in five major villages used in the present study (left). It varied considerably in plants of Maneydada and Rampuria villages. The pollination efficiency of large cardamom did not differ much across altitudes.

Pollination status

It is suggested that pollinators and pollination are decreasing all over the world. Unfortunately, we do not have a baseline data for making any projections or for our own awareness of the status of pollinators and pollination. Fortunately, we had a base line data for pollinators and open pollination efficiency – naturally occurring pollination due to the visits of pollinators as assessed by the amount of pollen grains deposited in stigma – for large cardamom from some of the sites that we used in the present investigation. That data was belonging to 2007 flowering season. We sampled for pollinators after ten years in those plots.

In both the years, we had some common and neighbouring sites for making the comparison robust. In both the years, we randomly plucked or field examined the stigma of flowers afternoon to score open pollination. With a dissection microscope it was possible to examine the stigma closely and score whether they were sufficiently pollinated or unpollinated without removing the flowers. We have also scored whether the pollen grains in the longitudinally split anthers were ever disturbed by the visitors to make predictions that the pollination deficiency may be due to poor visits of efficient pollinators and not due to the poor visits of bees which include both the robber and efficient pollinators.

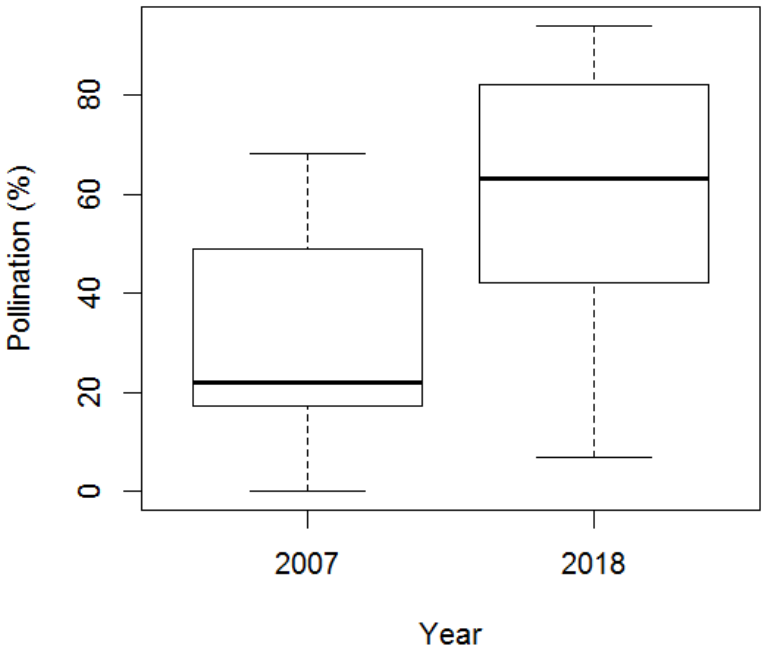
A closer look of anther stigma column to show an undisturbed anther and a virgin stigma



The closer photographs of stigma cup of large cardamom flowers. The left picture shows an unpollinated stigma, and the right one shows a sufficiently pollinated sitgma.

Table shows the sampling effort to assess open pollination efficiency in large cardamom flowers

Year	Number of locations	Total flowers	Mean number of flowers examined/site
2007	17	1611	94.76±63.71
2018	16	4331	94.6±31.82



Difference in open pollination efficiency in large cardamom in a decade in Darjeeling

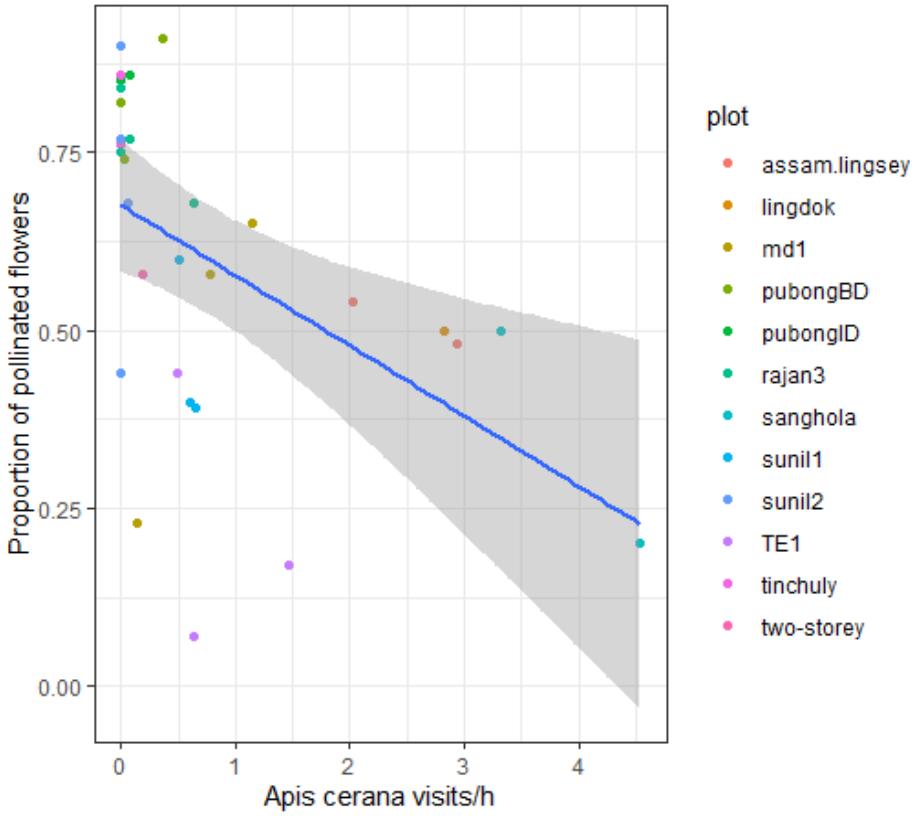
Our findings suggest that pollination has improved a lot in large cardamom over a decade. In 2007, only about 32% (N=1611) of the flowers examined were pollinated well by the bees. In 2018, this has increased to over 60%! This is an important finding for the Indian Himalayan Region. The pollination in large cardamom has increased *ca.* two folds in 2018 when compared to 2007 (t=-4.53, p=0.00006). It is likely that the population of specific and efficient pollinators of large cardamom, in particular *B. haemorrhoidalis* is not suffering from any natural or anthropogenic processes such as land use change and climate change. However, this needs a critical assessment in a future study.

The efficiency of different flower visitors

Our closer examination of over 8000 flowers in a period of four years (2018-2021) showed that honey bee is not a pollinator of large cardamom. We examined all these flowers when they were in the virgin phase and were sure that the flowers had received no visits of any other bees. Honey bees when began attending the flowers continue so for many hours in the early morning (5 AM to 12 noon). So, all our examination of stigma was immediately after one or several visits of honey bees to the flowers. We did not allow any bumblebees on our focal flowers which were used to examine pollination efficiency of honey bees. They were the major visitors of the flowers in the orchards that have honey bee boxes. In some places, their hourly visits to a single flower can be over thirty. Often several bees from the same colony attend the flower or clumps at a given point of time. None of the flowers that received the visits of honey bees was pollinated, even after the whole pollen grains were harvested by the bees. Because they have a relatively smaller tongue, they do not go for foraging nectar as

nectar is deep inside a longer corolla tube. So, they depend large cardamom flowers for the pollen resource.

A pollen foraging honey bee of *Apis cerana*. A copious amount of pollen grains can be seen on its body and corbiculum of the hind leg

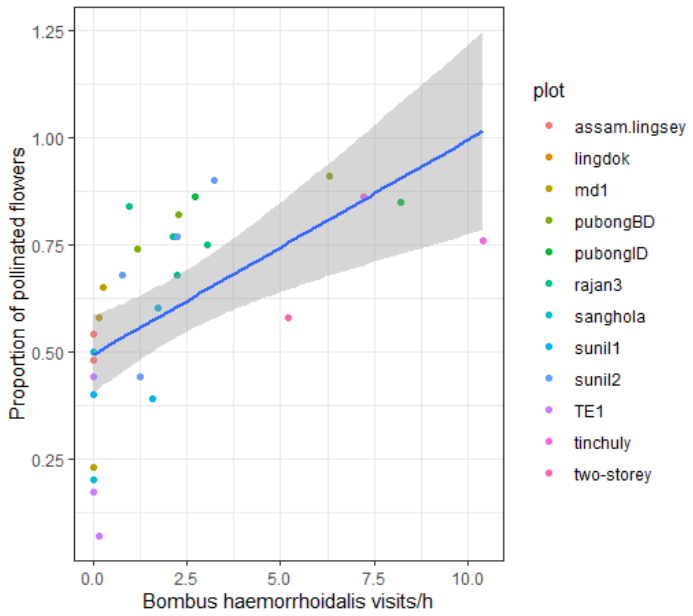


The open pollination efficiency decreases with the number of visits of honey bees to the plantations ($F=9.37$, $P=0.004$, $R^2=0.22$).

Bumblebees of *B. haemorrhoidalis* were infrequent to the flowers when compared to honey bees. Their visits to a single flower in a hour can be between one and ten. But our field

examination of over 2000 suggests that a single visit by a large queen may be sufficient for bringing out sufficient pollination in large cardamom. Yet we examined what is the optimum number of visits by a queen bumblebee for a desirable pollination outcome. For that we examined stigma of flowers after one or several visits of bumblebees.

A queen bumblebee is foraging nectar from a large cardamom flower. The thorax is laden by copious amount of pollen grains during the nectar foraging



Pollination efficiency of queen bumblebees increased with the visits of queen bumblebees. The results suggest that the pollination efficiency increases with the number of visits by queen bumblebees to the large cardamom flowers ($F=14.98$, $P<0.0005$; $R^2=0.32$).

Apart from these two species of bees, the crop in the altitudinal band 900 – 200 m asl attracted two more species of bees – *Bombus terrestris* and *Amegilla zonata*. Although we covered three flowering seasons, it is our surprise that these two species have interacted with the resourceful flowers only very infrequently. Both collected during the months of August and September – the summer months for the hills. It is therefore likely that the crop may get visits of more species of bees during the summer. Our random survey for the bumblebee diversity of the region also brought the evidences for only three species of bumblebees – an unidentified *Bombus* species, *Bombus terrestris*, and *Bombus haemorrhoidalis*. Although the flowers in wild might attract the visits of moths and sunbirds, our surveys did not find evidence for their visits. In low altitudes, we, however, saw many flowers colonized by the ants of *Paratrechina* and *Pheidole* species. They can threaten pollinators of large cardamom.

A sample of harvested fruits of large cardamom

Field vegetable crops

Apart from large cardamom, the villagers cultivate field vegetables, such as squash, pumpkin, cucumber, bitter-gourd, peas, mutter, round chilly, carrot, radish, onion, mustard, and potato. We watched flowers during some of their peak flowering to record their specific pollinators. Flowers of all these crops have interacted with the insects of some species. However, to our surprise only seven species of bees are interacting with the field vegetable crops of Darjeeling region of Indian Himalayan Region. Interestingly, hornet wasps, some yellow-jacket wasps, and many species of hover & blue bottle flies evolved as the major flower visitors of these crop species. All the forest villages were served predominantly by one species of bumblebee – Bombus haemorrhoidalis. During our casual survey in the fringes of the forests, we found nest activity of two more species of bumblebees, *B. luteipes* and *B. terrestris*. Interestingly, neither of them visited the flowering plants of the village premises. A list of flower visitors to major field vegetable crops has been given below:

List of crop species and their pollinators ordered by their dominance on flowers

Crop type	Visitors/ pollinators
Pumpkin	*Bombus haemorrhoidalis* (bumblebee)> *Apis cerana* (honey bee)> *Lasioglossum* sp (solitary bee)> *Halictus* sp> hoverfly sp1 among 14 species of insects interacting
Squash	*Apis cerana* > *Bombus haemorrhoidalis* > hornet wasp > *Lasioglossum* sp among seven species of insects interacting with the crop
Cucumber	*Bombus haemorrhoidalis* > *Apis cerana* > *Lasioglossum* sp among three species of insects interacting with the crop
Bitter-Gourd (Chuche-Karela)	*Bombus haemorrhoidalis* > *Apis cerana* > hornet wasp among the three specie of insects interacting with the crop
Buffalo bean	*Bombus haemorrhoidalis* among two species of insects interacting
Tree Tomato	*mbus haemorrhoidalis* among two species of insects interacting
Round Chilly	*Apis cerana* > *Lasioglossum* sp
Runner bean	*Bombus haemorrhoidalis* alone
Mustard	*Apis cerana* > hoverflies > calliphorid flies among sixteen species of insects interacting with the crop. This crop was attracted by many species of hoverflies (See below for a plate)
Tea	*Apis cerana* > *Halictus sp* > *Bombus haemorrhoidalis*

Among these vegetable crops, cucurbitacean crop plants such as pumpkin, squash, and cucumber and beans – buffalo bean and runner bean – are particularly benefited from the visits of bumblebees. Interestingly, bumblebees hardly visited the flowers of round chilly, mustard and tea, despite they were abundant. According to our surveys, they are honey-bee plants. Mustard was also a hover-fly plant as a minimum of seven species of hoverflies have used the pollen and nectar source of mustard.

We have taken pumpkin as a case species in the vegetable crops to study the dynamics of pollination and to study the role of flower expression on fruit set. Pumpkin is a monoecious plant and produce male and female flowers on two different nodes. We have undertaken our study in four forest villages, where we daily monitored the flowers produced

by selected pumpkin plants to understand what proportion of the total flowers is produced male flowers. This is an important awareness for the farmers as their feeling is that “pumpkin produces a lot of flowers, but sets very few fruits, and whatever has been produced is eaten by the pigs and other wildlife”. In my interaction, it was clear that the farmers have no awareness of monoecy in pumpkin and other cucurbitacean plants. So, with the involvement of the local farmers, we recorded the number of male and female flowers opened daily to predict a realistic fruit set in pumpkin.

Accordingly, we counted a total of 14,622 flowers for a period of about 3 months from four different fields. Out of this 14,518 were male flowers. This suggests that 99.3% of the total flowers produced by the plants are male and only 104 flowers out 14,622 are available for setting fruits! Although it is known from my south Indian study that pumpkin is male-skewed plant, there 10-20 percent of the total flowers produced were female. Among them, we monitored 38 female flowers to study fruit set. Although all of them have initiated fruit set as assessed on 5^{th} day of female flower opening, only 80% of them were set into mature fruits as assessed on 30^{th} day of setting female flowers. Twenty percent of the female flowers were aborted. Although we examined whether the number of male flowers in the field was a driver of fruit set, the model suggests that number of staminate flowers in the field is an irrelevant driver of fruit set in pumpkin (Chi-square=0.37, p=0.54). The fruit set was als not varied among the sites (P=0.32).

A pumpkin field of a forest village in Darjeeling

Field staff assessing fruit and seed set in pumpkin

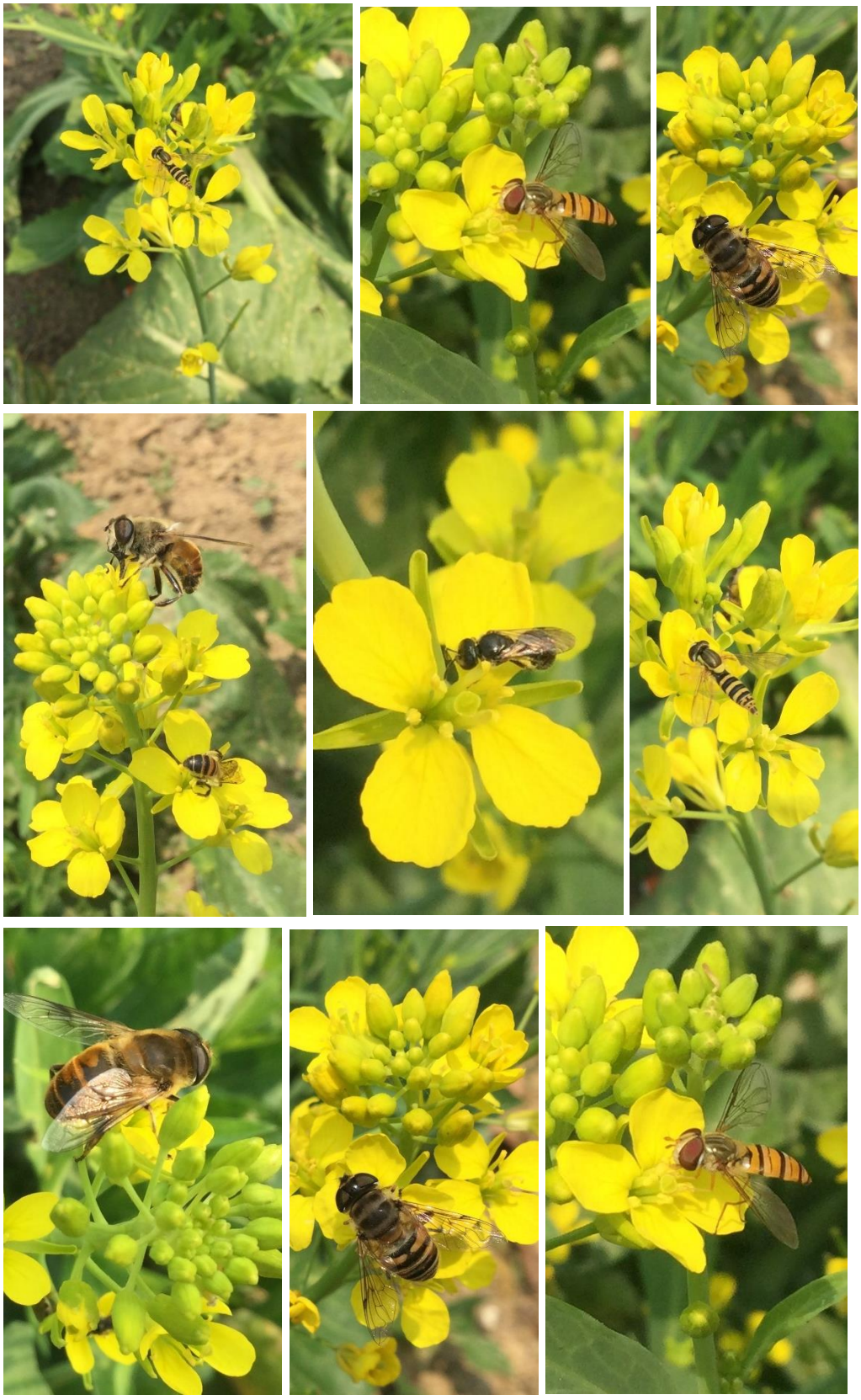
Seeds of two varieties of pumpkin

Squash flowers are pollinated predominantly by bumblebees

Pea plants are pollinated predominantly by bumblebees

Runner bean is pollinated predominantly by bumblebees

Cucumber is predominantly pollinated by bumblebees



Mustard is predominantly pollinated by hoverflies, honey bees, and *Lasioglossum* sp

Ornamental plants and weeds for pollinator conservation

We made a general survey in the premises of the forest villages to find what ornamental plants the dwellers bring and what weed species grow in fields help in conserving bee/ fly pollinators. Accordingly, we found a good number of such plants giving resources for bumblebees, honeybees, solitary bees, and hover flies – the four pollinator guilds of the villages.

Among all these ornamental plants, we recommend *Cuphea hyssopifolia* as the major honey bee plant. It is a hedge plant and produce flowers throughout the year in the mountains. They can be resourceful for the apiculture during the lean flowering period of winter. In one village, I have witnessed this one planted all along the avenues and in the premises of all houses and other institutions, such as primary schools, churches, play ground, and even the hedges of vegetable fields.

For bumblebee – *Bombus haemorrhoidalis* in particular – conservation, we recommend *Cestrum elegans, Fuchsia magellanica*, *Dahlia pinnata*, *Hibiscus* sp, *Rhododendrum* spp, and *Tropaeolum majus*. Among them, *Cestrum elegans* is most important one. They flower during April – November and give nectar constantly to bumblebees. Since they are tubular flowers, no other pollinating bees or flies are benefited form them. They must be planted all along the hedges and along the avenues as a second row to *Cuphea hyssopifolia* for conserving bumblebees.

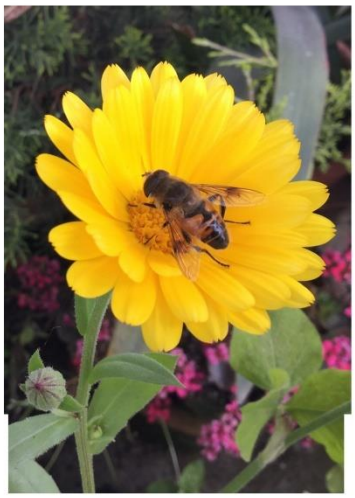
Hoverflies – a predominant guild of pollinators of the mountains and alpine climate – can be conserved by many generalist flowers belong to Asteraceae. Among the weeds and ornamentals, *Angelica sp, Calendula officianalis, Erigeron karvinskianus, Persicaria chinensis, Pseudonaphalium affine, Sedum rupestre, Taxacum, campylodes,* and several other species and subspecies of *Persicaria* can conserve hoverflies. However, mustard is the most important crop plant benefited from the visits of hoverflies. Therefore, mustard can remain the most important fly plant for the villages.

A pictorial guide of such plants is given below:

Angelica sp.

Barbarea vulgaris

Boerhaavia diffusa



Calendula officinalis

Camellia sinensis

Cestrum elegans

Cuphea hyssopifolia

Dendranthema grandiflorum

Digitalis thapsi

Erigeron karvinskianus

Eurya sp.

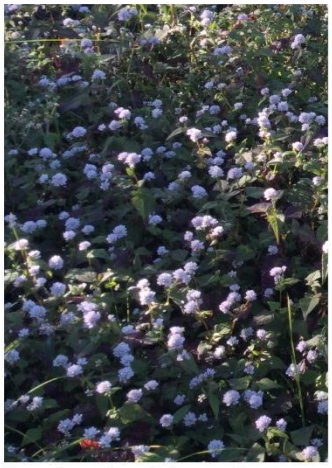
Fuchsia magellanica

Fuchsia Magellanica

Gasteranthus delphinioides

Ornithogalum thyrsoides

Pericallis cruenta



Persicaria chinensis

Persicaria sp.

Pseudognaphalium affine

Rhododendron lapponicum

Schizanthus pinnatus

Sedum rupestre

Taraxacum campylodes

Tropaeolum majus

Bergenia ciliata

Cannabis sativa

Casearia sp.

Commelina erecta

Commelina virginica

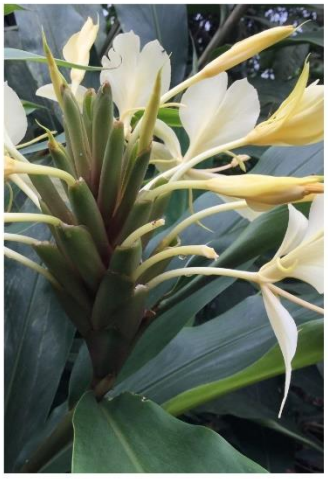
Costus sp.

Cyclanthera pedata

Cynotis sp.

Dicliptera sp.

Gasteranthus wendlandianus



Hedychium flavescens

Impatiens sp.

Ipomoea indica (Burm.) Merr.

Justicia carnea Lindl.

Persicaria capitata

Persicaria orientalis

Persicaria sp. capitata 1

Persicaria sp. capitata 2

Pisum sativum

Primula malacoides

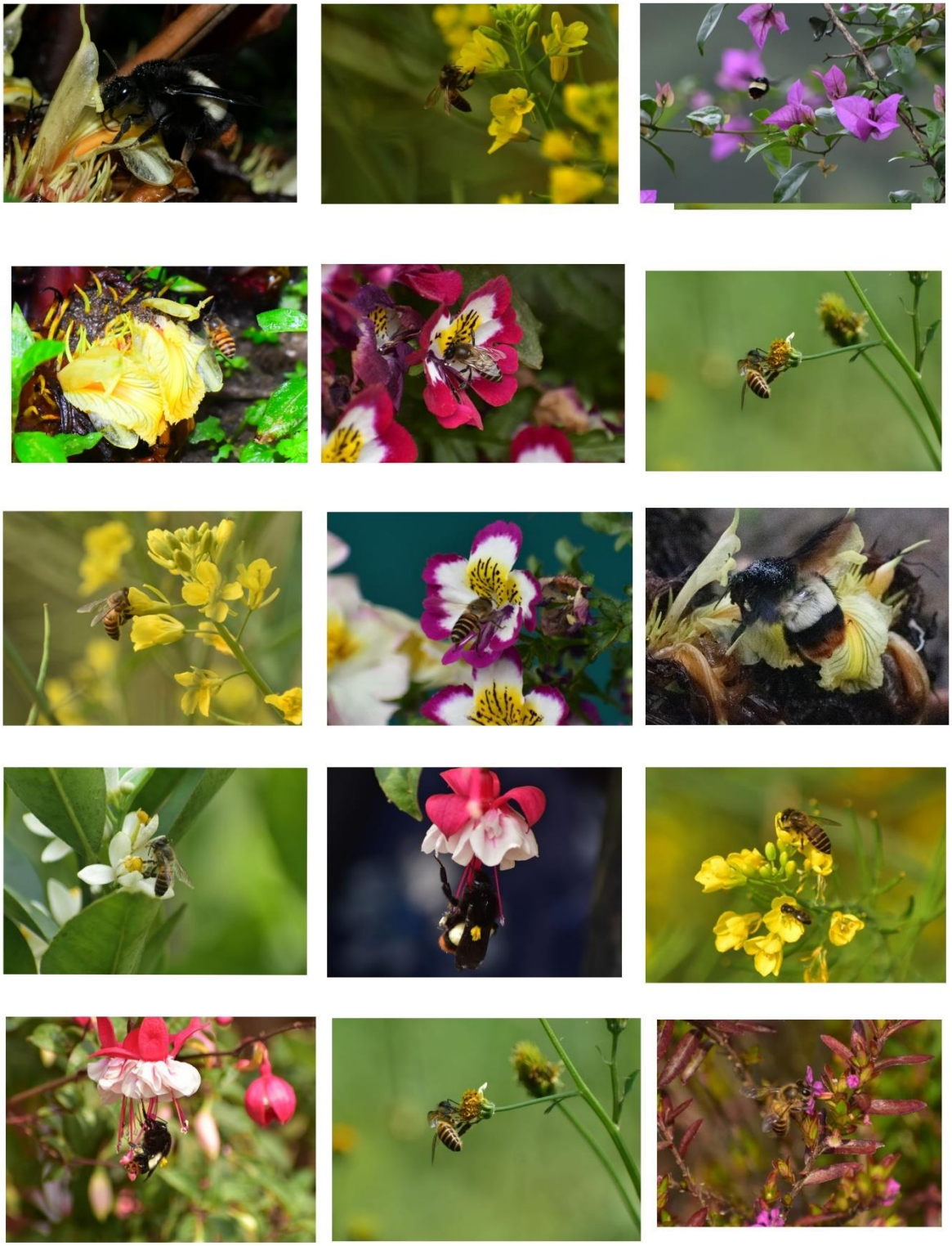
Rhododendron ferrugineum

Sechium edule

Solanum betaceum

A tea flower in the Rampuria forest village is being used by Apis cerana and a solitary bee

A Dahlia flower is a good bumblebee forage plant



Plat shows pollinator activities on different flowering plants in forest villages of Darjeeling

Pollinator awareness, demonstration plot, and livelihood dimensions

We propose the village of Rampuria as a pollinator awareness and demonstration plot in the present study. We propose this for three major reasons. First, it is a major field site of many research activities run by various other institutions. Second, a good number of tourists flow through the village as part of homestays and ecotourism activities. Third, sustainable agriculture in small holdings is still a major source of revenue.

We made a questionnaire survey to quantify the livelihood support the farmers may be getting directly from agriculture in order to assess what proportion of such crops are benefited from the pollination by bees and flies. Accordingly, we found that a household may be obtaining a monetary benefit of selling vegetables, cash crops, and honey in tune of about Rs. 51,000/ per household. Large cardmom contribute predominantly to this, about 50%. Interestingly, this is a crop benefited from the cross pollination by wild pollinators, and not by the managed honey bees. The wild pollinator is bumblebee. So, conservation of bumblebee foraging and nesting habitat should be the priority to support sustainable agriculture in Darjeeling villages.

Honey is a major commodity that fetches about 8% of the total revenue from agricultural activities. It costs Rs. 600-800/ kg, and farmers harvest 2-3 times per year. One harvesting happens immediately after the flowering season of large cardamom ended. Honeybee and apiculture are benefited predominantly from large cardamom flowers, but large cardamom did not benefit from their visits. Honeybees can even reduce the effect of bumblebee pollination by exerting competition pressure to bumblebees for resources. So, it is very difficult to make a proposal here. We suggest maintaining honey bee colonies far from the fields of large cardamom. When bumblebee activity is higher, maintaining honeybee colonies may not bring any harm.

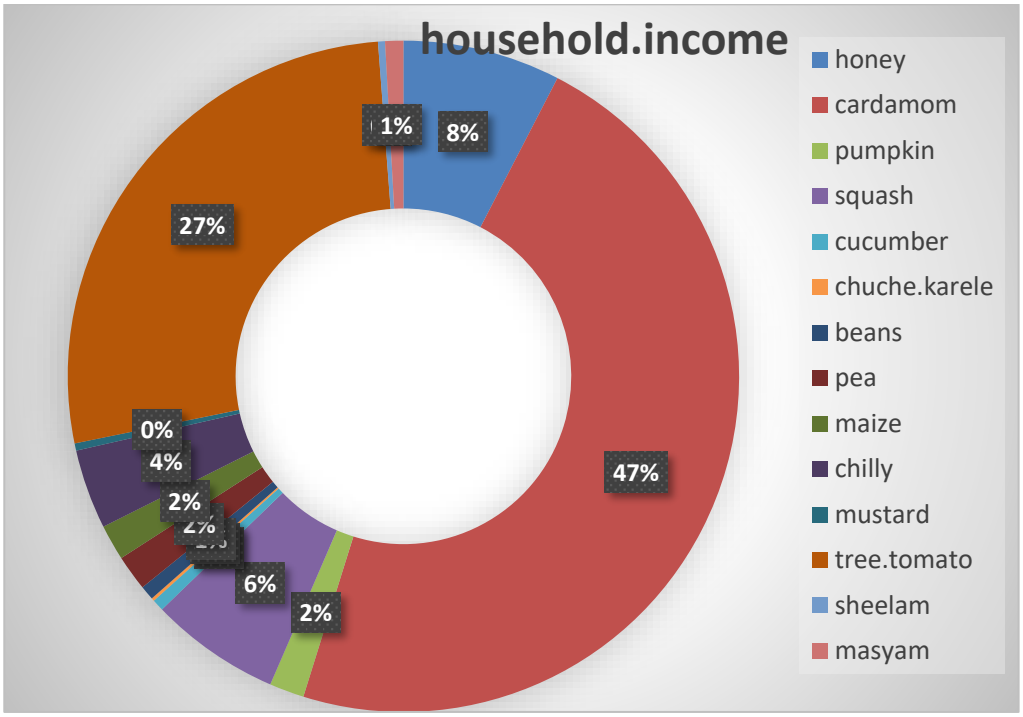
Chilly is a major crop fetching Rs. 400- 500 per kilo. So, many farmers are changing the land-use pattern from large cardamom to chilly. The reason they cite for this shift is that they receive very little support form the Spices board of India for cultivation of large cardamom. No new plant varieties less susceptible to microbial pathogenesis to the plants are so far came. Although a famer can get Rs. 700 – 800 per kg of large cardamom, the market is highly fluctuating. If large cardamom is replaced, it can be a major setback for the sustenance of Bombus haemorrhoidalis – the bumblebee. Because, this crop is a major food plant for them for about 4-5 months, and particularly during the initial over-wintering months.

Tomato (green-house) and tree tomato are the other major sources of revenue for the farmers. Tree tomato is benefited from the visits of bumblebees. Onion is also benefited from the visits of bumblebees and honey bees.

Taken together, the village farms and farmers' income are benefited from the visits of both bumblebee and honey bee. While honey bees in all villages have their colonies managed by the farmers, bumblebees are wild in nature. Conservation of them require both nesting and foraging sources. According to some farmers, they have managed several occasions for managing bumblebees too in wooden or earthen pots. While there was some success, propagation was difficult.

Farmers through our research and participatory activities are aware of the importance of pollinators in their livelihood and food security. Some critical knowledge gaps were there on the efficiency of the pollinators and plant reproductive biology to the farmers. For instance, farmers were informed by the concerned stakeholders that honey bees are the efficient pollinators for large cardamom. In fact, that was against the fact. According to our study, honey bees are mere robbers for large cardamom, but a trustworthy pollinator for round chilly. Farmers themselves were trained to distinguish a pollinated flower from an unpollinated flower, and equipped them to prepare for expecting a realistic crop output.

Farmers were not aware that cucurbitacean crop plants are male-skewed. So they were thinking that the crop failure in pumpkin and other gourds are due to climate change. Our study unequivocally suggest that honey bee can't be promoted as a universal pollinator of crops.



Pie chart shows the revenue generated from each of the major agricultural product. The average income per household is calculated to be Rs. 51,568 (±67276 SD)

A demonstration time to the farmers. On the right, anther-stigma column of an unpollinated, yet heavily honeybee foraged flowers is shown.

Bee genetic resources, traditional knowledge and conservation of pollinators in forest villages

Farmers have been asked directly and indirectly for understanding their knowledge on pollinators and their involvement in conservation of pollinator genetic resources in Darjeeling. We have undertaken this with 120 farmers in Rampuria, Maneydara, Rambi, Tinchuly, and Pubong areas.

All the villages had several honeybee boxes. They have been maintained for honey (100%), pollination (20%), and for both (80%). Few of them (30%) are giving up apiculture due to unpredictable weather and hornet attack to the bees. Although 72% of the respondents are aware that honey bee is a wild species and nest in tree cavities, none in the sampled villages at present has a wild nest of *Apis cerana*. However, a village outside our major sampling plot has one such nest. We made a glass box for housing a colony of honey bee as an education tool, and promoted this as an outreach and livelihood activity for the villagers.

Farmers (100%) are aware of the presence of two species of bumblebees in Darjeeling. *Bombus haemorrhoidalis* and *Bombus terrestris*. But almost everyone agrees that only one species is abundant in the premises of the villages. They have seen the second bee during their firewood collection trips to the reserve forests.

About 90% of the farmers are aware that bumblebees nest in ground, and have seen the colonies of bumblebees. Over 60% of them have seen them only in the forests, remaining have seen them both in forests and premises of the villages. Only 2% of them have attempted to manage bumblebees in cages, but did so only occasionally. To our question, "are bumblebee population declining?" 28% of them said "yes", 70% said "no", and remaining people are not aware of it.

Our research findings agree to most of the traditional knowledge. We have got evidences for three species of bumblebees – *B. haemorrhoidalis*, *B. terrestris*, and *B. luteipes* – in the forest villages of Darjeeling. We also have encountered only *B. haemorrhoidalis* as abundant, and *B. terrestris* very rarely in the village premises; *B. luteipes* was encountered rarely in the fringes of forests. Apart from bumblebees, the domesticated honeybee was the second abundant bee in the villages. The villages also had nine more species of bees – *Lasioglossum* sp, *Halictus* sp, *Hylaeus* sp, *Colletes* sp, *Amegilla zonata*, and two species of *Trigona*, and Xylocopa sp, and Megachile sp. The latter five species were collected only from the low altitudes (900-1000 m asl).

Farmers keep ornamental plants only for aesthetics and not aware that they can be a resource for the bees. However, we found evidences for their role as a forage plant of bees. They were not aware that even ornamental roses can help in conserving bees. Our research that includes the samples from the NMHS project sites of Darjeeling show that the leafcutter bees use ornamental roses as an important nesting resource.

None of the farmers is aware that hoverflies can be efficient pollinators for some of their crops, but 56% of them didn't distinguish the hoverflies from honeybees!

Forest villages are beautiful with the ornamental plants, many of these plants feed honey bees, if not bumblebees. A village boy is posing with an ornamental rose

Evidences for ornamental roses used by the bees for nesting activities

A house with a wild nest of a honey bee – *Apis cerana*

A demonstration bee hive of honey bees in the Rampuria Pollinator demonstration plot

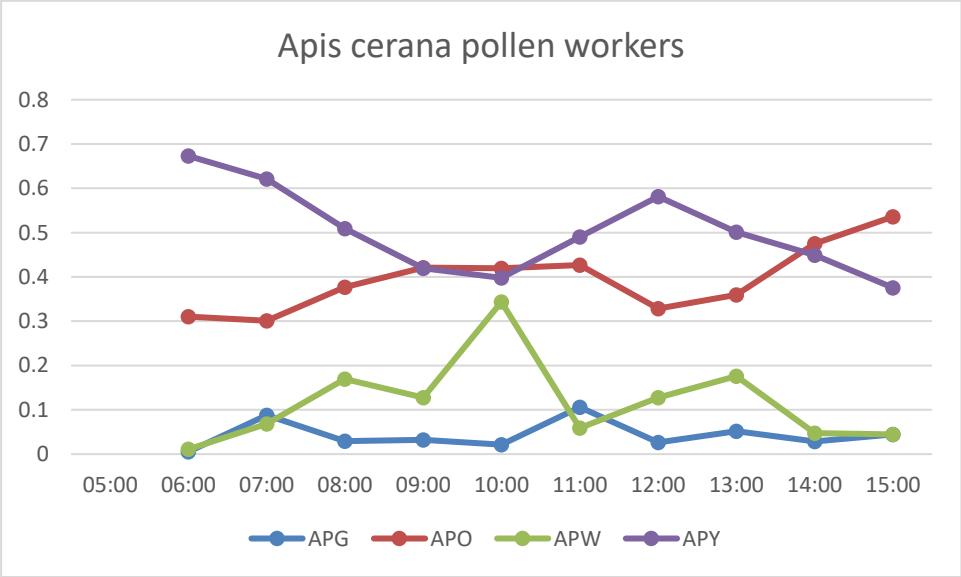
Nest activity of honeybees and bumblebees

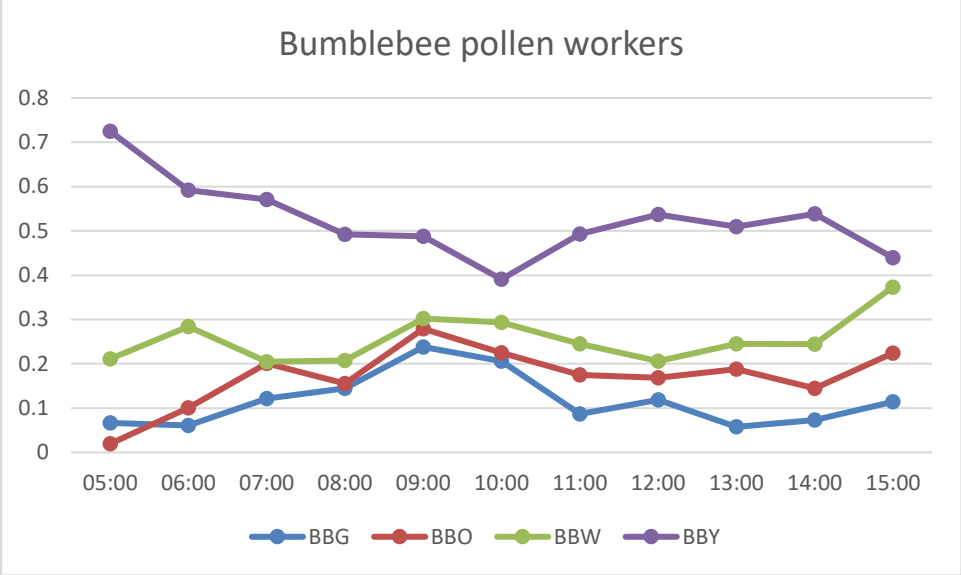
It is important to know where bees go and what bees bring to their nest to understand their foraging resources. We made a very pilot study to record the foraging sources from our nest activity studies. First, we surveyed premises of the forest villages and unearthed fourteen colonies in the villages. We studied what is the color of the pollen pellet for the workers that return to nest. All these observations were made during November 2021.

A total of 2880 pollen-bearing bumblebees was watched over four nest different nest holes during 0500-1600 h. The observations were made hourly. The hourly entry was ranged between 21 and 177 with a mean of 57.6 entries (114.8 SD) per hour. The highest entry ranged between 105 and 177. The other entry ranges was 21-54, 38-148, 52-71, 37-57, and 25-53. However, the total (including pellet less workers) bee entries ranged between 69 and 280 (mean=136, SD=48).

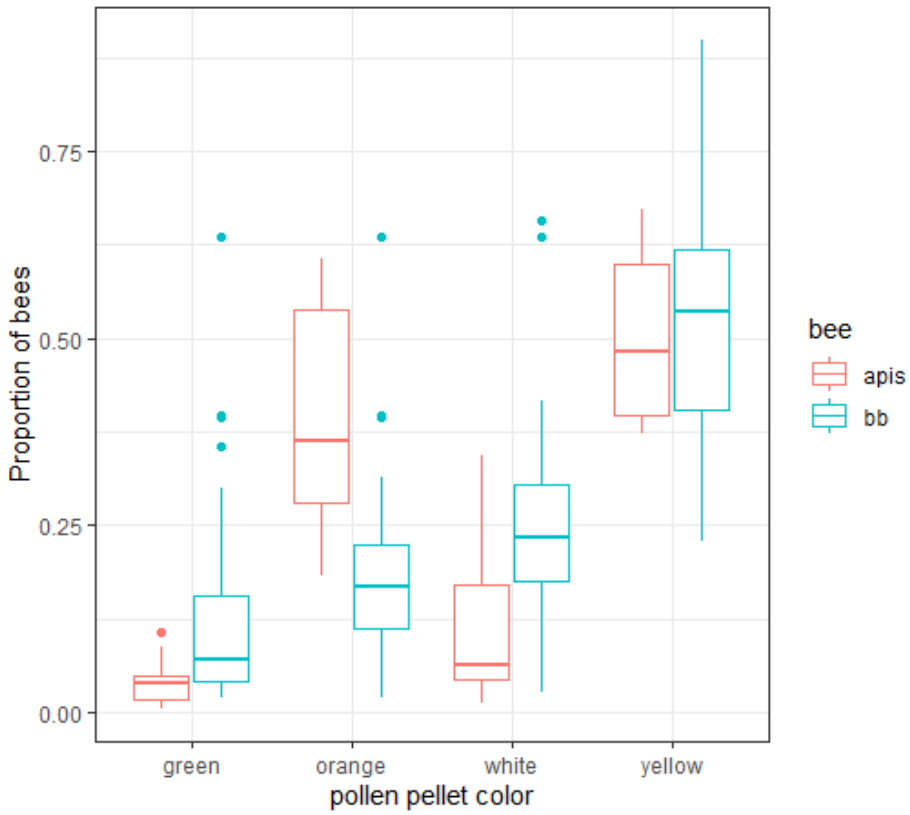
A total of 4660 pollen-bearing honey bee visits was recorded for two different hives. The hourly range for the two nests was 79-521 entries with a mean of 259 visits (131 SD) and for each of the nests was 79-392 and 85-521.

Both the bees used the forest trees (yellow pollen) for pollen harvesting. However, honeybees also depended the Tea flowers for pollen grains. Proportion of bumblebees returned with tea pollen was relatively lesser than the honey bees (GLM.Binomial: -1.12±0.61, Z=-1.82, P=0.06). The proportion of bees returning with other pollen types was not significantly different for bumblebees and honey bees (Green: 1.24±1.39, Z=0.9, P=0.37; White: 0.98±0.97, Z=1.03, P=0.37; yellow: 0.09±0.54, Z=0.2, P=0.8). The results suggest that both the species of the bees competed for the same resources.





Line plots show the proportion of returning worker honey bees and bumblebees with different pollen pellets over different hours of a day. Both have preferred a flower that produced yellow pollen grain.



Box plots show the variation in the worker honey bees and bumblebees returning with different coloured pollen pellets

A screenshot from the video of a wild bumblebee nest. In the bottom picture, two workers can also be seen

A wild nesting habitat of a *Bombus haemorrhoidalis* colony.

A worker bumblebee on the nose of a research staff engaged in studying bee activity

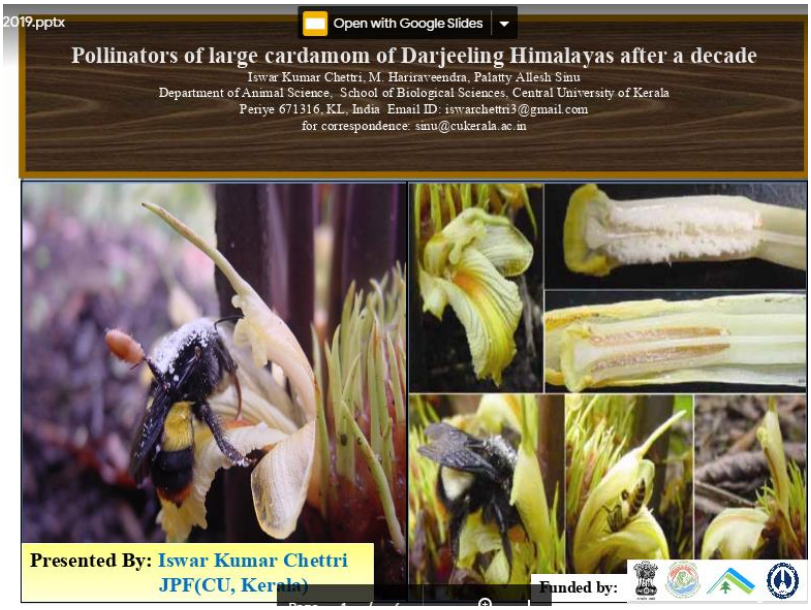
Outreach

You can view a video of our work in the following link

https://www.youtube.com/watch?v=4MLuOjcEqjE&t=6s

A sapling of Golden-Shower plant (Cassia fistula) brought from the plains to the bee demonstration plot to show leafcutter bee foraging of leaves. All the cuttings on the leaves are made by the bees in the lowland. In the highland, this plant did not survive due to freezing cold. Our study on leafcutter bee marks on ornamental roses – a common leafcutter bee plant – yield no damage in the hills. It suggests that the activity of leafcutter bees is very poor in the hilly tracts of IHR.

Research staff is planting a bee-friendly plant in Rampuria forest village



A presentation in ZSI

A research student bagged first prize in the National seminar on Pollinators organized by ZSI - Kolkata