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Entomophilic pollination of *Foeniculum vulgare* Gaertn

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Abstract
The seeds of *Foeniculum vulgare* Gaertn. (Apiaceae) are used as spice as well as important medicinal purpose which is also famous in Bengal as Pan-mouhri as it is also used with beetle leaf. The seed production is depended on the successful pollination where insects played a major role as pollinators. Present investigation deals with the flower-visitors (insects) interaction, pollen production, pollen dispersal and pollination of *Foeniculum vulgare* Gaertn. The yellowish flowers appear during December - March. Flowers generally open in the morning (05:30-07:00 hrs.) and anther dehiscence takes place after flower opening. Each bisexual flower contains 5 anthers which produce a total 9850 pollen grains in average. After flower opening different insect flower visitors like members of Diptera (Flies, Syrphid flies), Hymenoptera (*Apis dorsata*, *Apis cerena indica*, *Xylocopa* sp., *Amegilla* sp., *Vespa* spp., Wasps, Ants etc.), Lepidoptera (Butterflies) and Coleoptera were found to visit the flowers for collecting their forage. During their visit they carry a considerable amount of pollen grains and transfer to other flowers for successful pollination for seed production. Among the visitors *Apis* spp. and *Vespa* spp. pay continuous visit for enhancing the pollination rate. The fruit production is considerably low when the insects were excluded which suggested the significant role of various insects for successful pollination.

Keywords: flower- visitors, *Foeniculum vulgare*, fruit set, insects, pollen dispersal, pollination

Introduction
Floral visitor insects are dependent upon nectar and pollen for their nutrition. Among different groups of flower visitors' insects are predominant. They visit to millions of flowers and have been considered as potential pollinators following the rules governing co-evolution and pollination systems between conspecific plants and their pollinators (Bhattacharya and Mandal, 2000) [5]. Lack of adequate floral resources may lead to weak interaction between plants and their appropriate pollinators, which in turn causes lower limits of flower visits and pollination success.
Pollination is a vital phenomenon in the sexual reproduction of flowering plants. It is a simple process of transferring of male sexual parts to the female reproductive structure of a plant. This process involves three phases- release of pollen, transfer of pollen grain with the help of certain vectors (biotic or abiotic) and placement of pollen for effective fertilization, all of which occur in succession. Faegri and Van der Pijl (1980) [12] provided a number of examples on floral visitors, floral resources and its dependence upon pollination and fruit set. There might have a correlation between nectar secretion and entomophilous nature of dioecious plants. Role of foraging dynamics and floral sex allocation on fruit set of certain plants were documented by Brunet and Charlesworth (1995) [6] and Willis and Kevan (1995) [32] respectively. Dafni and Giurta (1999) [9] reported about functional significance of plant-pollinator interactions in relation to floral symmetry and nectar guides. Lughadha and Proenca (1996) [16] showed increased pollinators population in presence of nectar and pollen abundance. Strauss (1997) [29] showed the relation between floral characters, pollinators and plant fitness; while Dafni and Giurta (1999) [9] enriched the literature by focusing the functional ecology of floral guides in relation to insect behavior and vision. Reproductive system of Apiaceae has been investigated by Bell (1971) [3], Webb (1979) [30], Lindsey (1982) [14], Schlessman (1982) [28], Koul *et al.* (1989) [13], Shilpa *et al.* (2014) [27] and Bharti *et al.* (2015) [4]. These investigations notwithstanding the interaction between flower-visitor interaction and pollination in *Foeniculum vulgare* of the family Apiaceae have received little attention. Our observations on *Foeniculum vulgare* have generated results which highlights this interaction.
Thus the present investigation has been done to determine the relation between the floral biology and insect flower visitor interaction.

Materials and Methods
Foeniculum vulgare Gaertn. is under the family Apiaceae or Umbelliferae is very common cultivated plants has grown all over the West Bengal. The study was conducted following the method of Mathur and Mohan Ram (1986) [18], Reddi *et al.* (1989) [24] and Mondal *et al.* (1992) [20] to observe different phenological events of same species growing at around Bolpur-Santiniketan, Birbhum (23.6712° N, 87.6919° E). Following Mandal and Chanda's approach (1981) [17], the number of pollen grains per anther and per flower was measured. A pollen ovule ratio of a flower was calculated by the method of Cruden (1977) [8]. Pollen viability has been evaluated by T.T.C (2,3,5- tri phenyl tetrazolium chloride) staining techniques (Dafni and Firmage 2000) [10]. Netting and bagging of flower was carried out to determine the role of air and insects in pollination by Reddi and Janaki Bai (1981) [23].

Results and Discussion
These plants are erect annual herbs and having some medicinal property. In India and neighboring countries, the seeds of the plants are used as masticatory and for chewing alone or in betel or paan. Additionally, it is used for thirst,

flatulence, colic, coughing, and to flavour soups, meat meals, sauces, bread rolls, pastries, confections, liquors, and pickles. (Pruthi 1976) [22]. Extracts of fennel seeds have been shown in animal studies to have a potential use in the treatment of glaucoma, as a diuretic and a potential drug for the treatment of hypertension (Agarwal *et al*. 2008) [1], antioxidant activity (Ruberto *et al*. 2000) [25], anti-diabetic activity (El-Soud *et al*. 2011) [11].

To treat earaches, toothaches, coughs, asthma, and rheumatism, seeds are used in pharmaceuticals as a stimulant, stomachic, carminative, and stomachic agent. It is also used in the treatment of diseases of the chest, spleen and kidney and as a good vermicide against hookworm.

The yellowish, actinomorphic, bisexual, epigynous flowers in compound terminal umbels. Flowers open at early morning (05:30 hrs. – 07:00 hrs.) during the period of December - March. Flower contains nectar with specialized aromatic scents.

Flower contains reduced calyx, petals-5, yellow. Stamen-5, larger than petals, anther dehisced longitudinally after flower opening. Each flower produced 9850 number of pollen grains. Gynoecium consists of 2-carpels with short style, stigma two, capitates, two celled inferior ovary with one ovule in each chamber. Pollen – ovule ratio is 4925:1. The pollen ovule ratio also suggests the xenogamous nature for which the vectors are essential (Table-1).

Plants of *Foeniculum vulgare* are strongly protandrous. The staminate and pistillate phases mature at different timings within the flower as well as in the umbel. Before the stigma is receptive, pollen is discharged. Separation of male and female phases or dichogamy is a contrivance for promoting cross-fertilization (Lloyd and Webb 1986) [15]. Protandry segregates presentation of pollen and stigmas are presented simultaneously in different flowers of the same plant and pollinator activity may lead to geitonogamy (Webb and Littleton 1987, Koul *et al*. 1989) [31,13].

Chaudhary (2006) [7] studied that about thirty-nine species visited the crop, among this species under 47.1 % in Hymenoptera and 50.3% in Diptera, *Apis mellifera* (39.5%) and *Episyrphus balteatus* (32.5%) was the most dominant among the Hymenoptera and Diptera.

Pollinator diversity and abundance was studied on fennel (*Foeniculum vulgare*) and it is recorded that sixteen species of insect visitors on the flowers of fennel. Of these, twelve species belonged to hymenoptera, two to diptera and one to lepidoptera. The foraging activity of *Apis cerana* and *Apis florea* started from 07:00 hrs. and continued up to 18:00 hrs. dominantly. Whereas, the activity of *Tetragonula iridipennis* was observed one hour late (08:00 hrs) and continued up to 16:00 hrs. (Shilpa *et al.* 2014) [27]. Pollination by honeybees not only increases the yield, but also enhances hybrid vigour, creates variation and maintains the gene flow in the ecosystem there by conserving the diversity in crop varieties (Melnichenko 1977) [19].

Biodiversity of pollinators on fennel reveals twenty five insect species belonging to fifteen families of five orders were recorded from fennel flowers, in which, seven belong to reserve Lepidoptera, nine belong to Hymenoptera, five belong to Diptera, three belong to Coleoptera and one belong to Odonata. Among the insect pollinators; *Apis florea*, *Apis cerana indica*, *Apis mellifera* and *Apis dorsata* were the most frequent pollinators. Among different bee species, the maximum mean population observed in case of *Apis florea* followed by *Apis mellifera* and *Apis dorsata*, whereas, the least abundance was observed in case of *Apis cerana indica*. Among different *Apis* species, *Apis florea* spent maximum time followed by *Apis mellifera* and *Apis cerana* (Bharti *et al*. 2015) [4].

Earlier studies of Youngken (1950) [33], Sagar (1981) [26] and Baswana (1984) [2] also indicated that *Apis florea* and *Apis mellifera* were the chief floral visitors of fennel respectively. Narayanan *et al*. (1960) [21] noticed that, bees were the primary pollinators of fennel and *Apis florea* constituted 81% of the visitors and play a vital role in successful pollination.

Whereas after flower opening, different flower visitors like members of Diptera (Flies, Syrphid flies), Hymenoptera (*Apis dorsata*, *Apis cerena*, *Apis indica*, *Xylocopa* sp., *Amegilla* sp., *Vespa* spp., wasps, ants etc.), Lepidoptera (Butterflies) and Coleoptera were found to visit the flowers for collecting their forage (Table-2). Compound terminal umbels easily helps in landing the visitors over flower and as well as attractant. Among the flower visitors *Apis* and *Vespa* are most abundant (Table-2), which helps in pollen dispersal directly by carrying a considerable amount of pollen grains attached to their body parts and enhancing the pollination rate. The comparison between the fruit set in natural as well as netted condition also established that the role of insects in successful pollination.

Conclusion

The studied plant is very much dependent upon several types of insects as pollinators. It is clearly understood that for successful pollination of *Foeniculum vulgare*, visiting time of pollinators is equally important for transfer of pollen grains after anthesis. The understanding of such flower-visitors interaction will be helpful for pollination biology study as well as conservation of biodiversity.

Table 1: Floral Characters of *Foeniculum vulgare* Gaertn

Floral Characters	Observations
Flowering period	December - March.
Flower type	Actinomorphic, Bisexual
Flower colour	Yellowish
Flower opening time	05:30-07:00 hrs
Nectar	Present
No. of anthers/ flower	5
Anther dehiscence mode	Longitudinally
Average no of pollens/anther	1970
Average no. of pollen grains/flower	9,850
No. of ovules/flower	2
Pollen/ ovule ratio	4925:1
Pollen shape	Per-prolate
Pollen type	3-colporate

Table 2: Flower Visitors of *Foeniculum vulgare* Gaertn

Sl No.	Visitors	Visiting time	Forage Materials
1.	*Amegilla* sp. (Hymenoptera)	Day	Pollen and Nectar
2.	*Apis* sp. (Hymenoptera)	Day	Pollen and Nectar
3.	*Xylocopa* sp. (Hymenoptera)	Day	Pollen and Nectar
4.	*Vespa* sp. (Hymenoptera)	Day	Nectar
5.	Ants (Formicidae)	Day	Nectar
6.	Flies (Diptera)	Day	Pollen and Nectar
7.	Syrphid flies (Diptera)	Day	Pollen and Nectar
8.	Butterflies (Lepidoptera)	Day	Nectar

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