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Pollination biology of *Terminalia chebula* Retz. in Delhi and Western Ghats

S. Talwar & A. K. Bhatnagar*

Environmental Biology Laboratory, Department of Botany, University of Delhi, Delhi – 110 007, India

***e-mail:** akbhatnagar49@gmail.com

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ABSTRACT

Terminalia chebula Retz. (Combretaceae), a deciduous tree of high economic value, finds its use in pharmaceutical and leather industry. Overexploitation and poor regeneration have led to its sparse distribution in nature. The present study has been undertaken with an objective to understand and compare the pollination biology of the tree in its native habitat at Dapoli (Maharashtra) and a few trees planted in Delhi. The tree flowers from March to May in Dapoli and from May to July in Delhi. Flowers are bisexual, pale yellow, actinomorphic, epigynous and arranged in dense spikes. Floral nectaries are present at the base of style. Anthesis begins at night with the style emerging out before the stamens. A flower has two phases: (1) female phase when stigma is receptive; (2) bisexual phase, when stigma remains receptive and anthers mature and dehisce. Such a type of mechanism is known as incomplete protogyny. Anther dehiscence is asynchronous, facilitating cross pollination. The tree is entomophilous with a wide variety of insects visiting the flowers. The major pollinators of *Terminalia chebula* are *Apis dorsata*, *Apis cerana-indica*, *Polistes hebraeus*, *Vespa orientalis* and *Eristalinus* sp. Diversity has been observed in pollinators visiting the flowers at Dapoli and Delhi. Results of breeding experiments show that plant is self- as well as cross-pollinated. Self-pollination too can occur only with the help of external agents as anthers and stigma are spatially separated. However, cross-pollination is more prevalent.

Keywords: Conservation biology, Floral mechanism, Pollination biology, *Terminalia chebula*

INTRODUCTION

Owing to their prolonged juvenility, large size, irregular flowering and inaccessibility of flowers for pollination experiments, tree species pose several difficulties to investigators working on reproductive biology (Bawa 1990). Reproductive stress is one of the major reasons leading to rarity of many plant species. It has been observed that wind-pollinated species are often facing reproductive/pollination constraints due to fragmentation and reduced population density (Knapp *et al.* 2001, Seltmann *et al.* 2009), and animal-pollinated species suffer in addition due to decline of their pollinators (Biesmeijer *et al.* 2006, Anderson *et al.* 2011, Sekercioglu 2011). Many keystone and endemic species are on the verge of extinction and need to be urgently conserved as their habitats are either being degraded or the species are being overexploited (Thakur & Bhatnagar 2013). For effective conservation, it is important to know genetic or ecological limitations to reproduction and propagation. Detailed information on reproductive biology of plant species is essential for developing effective strategies for conservation and sustainable utilization. Studies on reproductive biology are also important for selection, multiplication and genetic improvement of plants (Koul-Moza &

Bhatnagar 2007). Therefore, the present study has been undertaken to study the different aspects of reproductive biology (phenology, floral biology, pollination biology and breeding system) in its native habitat in Western Ghats and in a garden in Delhi.

Terminalia chebula, a member of family Combretaceae, is an economically important tree species growing in Western Ghats. It is one of the main constituents of 'triphala' which is regarded a panacea for stomach disorders. Triphala is reported to strengthen the different tissues of the body, prevent ageing and promote health and immunity (Juss 1997). Apart from medicinal value, tannins, extracted from fruits are also used in leather industry (PID 1972). Intensive and uncontrolled exploitation of its fruits, combined with low rate of natural regeneration, has led to drastic depletion of its natural populations. There is need to conserve and select genetically superior varieties for plantation to meet the demand of the pharmaceutical industry. Information on reproductive biology is fundamental in designing conservation programmes which may also help in preserving the genetic potential of this species.

In many parts of Western Ghats, old trees of *T. chebula* are observed but young recruits are rarely seen. The stockings of this tree are badly affected due to forest fire. Fire causes changes in soil composition, decline in strength of pollinators, and growth of invasive species which hinder regeneration of native plants (Gonzalez-Perez *et al.* 2004, Certini 2005, Brown & Johnstone 2012). As the fruit of *T. chebula* is a drupe with a hard endocarp, it requires a long period of time for the seeds to germinate, which is only possible with adequate soil moisture and humus. Since this particular species is found only on slopes of the Western Ghats, the trees often fall down in summers due to strong wind (Srivastava 2000). Poor natural regeneration in *T. chebula* has also been attributed to low rate of seed germination which has led to scarcity of the trees in their natural habitat. Sowing of seeds without any pre-treatment results in erratic, inadequate germination and low survival of the seedlings. These factors contribute to high production cost of seedling stock (Bhardwaj & Chakraborty 1994).

MATERIALS & METHODS

The study was conducted at Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Ratnagiri district in Maharashtra and at the North Campus of University of Delhi, Delhi. Dapoli is a small town situated at a height of about 244m above sea level in Ratnagiri district, Konkan on the coast of Maharashtra state (India). It is also called the Mini Mahabaleshwar because of its cool climate throughout the year. Konkan region is situated in the Western Ghats of Maharashtra which lies between 16°31' and 18°04' North and 73°02' and 73°52' East and occupies an area of 8196 km^2. The average rainfall during 2004-2006 was about 3000 mm, with 91% received in four monsoon months i.e. June to September. The National Capital Territory of Delhi lies between 28°12' and 28°53' North, and 76°50' and 77°23' East, with an elevation of 233 m above mean sea level. Due to its geographical location between Indo-Gangetic plains in the east, the Thar desert in the west, the Aravalli in the south and the Himalayas in the north, the Delhi state has a unique character of semi-arid climate with extremes of summer alternating with extremes of winter and moderate rainfall. The monthly mean temperature in Delhi is highest in June, touching 46-47°C during day time.

To study the phenology, onset of major vegetative and reproductive photoevents that occurred during the year were observed. Reproductive period was calculated from the day of emergence of the inflorescence or flower buds till the maturity of fruits. Six trees in Dapoli and three trees in Delhi were selected, and one hundred inflorescences were tagged at each location for daily observation. The increase in length and morphology of the inflorescence/flower were observed. Fifty inflorescences at random were tagged on different trees in the evening prior to anthesis and the number of open flowers in a day were recorded. Open flowers were removed to avoid recounting on the next day. Anther dehiscence was also recorded at a regular interval of 30 minutes. Fluorochromatic reaction (FCR) test (Heslop-Harrison 1970) was carried out to observe viability of pollen grains. Stigma receptivity was checked by the procedure described by Mattsson *et al.* (1974).

Experiments were carried out on selected trees to understand the mechanism of pollination, nature and the

activities of the pollinator, and the interaction between the plant and the pollinator (Faegri & Pijl 1979). Insects visiting the flowers were collected with the help of a net and were killed immediately by ethyl acetate vapour. The number of insects visiting the flower was recorded starting from 06.00h to 18.00h over a period for seven days. The number of visits made by an insect and the average time spent by an insect on the flower was recorded with the help of a stopwatch. Since the flowers were compactly arranged, the time interval between the successive movements of an insect within an inflorescence was taken as the time spent on a flower.

Preliminary investigations were aimed at study of fruit set following natural pollination, artificial self-pollination and cross-pollination. Possibility of existence of apomixis was also examined by withholding pollination.

RESULTS & DISCUSSION

Phenology—Phenology of trees growing at Dapoli and Delhi showed that the flowering season was short (five to six weeks), whereas fruiting season was long. In Dapoli, leaf shedding started in the first week of December and continued up to the end of February. The trees were completely devoid of leaves till the end of February. First vegetative buds appeared in the first week of March, followed by the initiation of floral buds. Flowering started in the last week of March and reached its peak in the second week of April. This phase was maintained till the last week of the month, and then the flowering started declining in the first week of May.

In Delhi, leaf fall started in first week of February which continued up to April. Vegetative buds appeared in the last week of April, followed by floral bud initiation. Flowering started in second week of May and continued up to the first week of July. Maximum flowering occurred in mid-June. Fruits started developing in the last week of June. Phenoevents at Dapoli and Delhi have been compared in Figure 1.

Variation in the relative occurrence of phenoevents in *T. chebula* growing at Dapoli and Delhi can be associated with the difference in temperature and

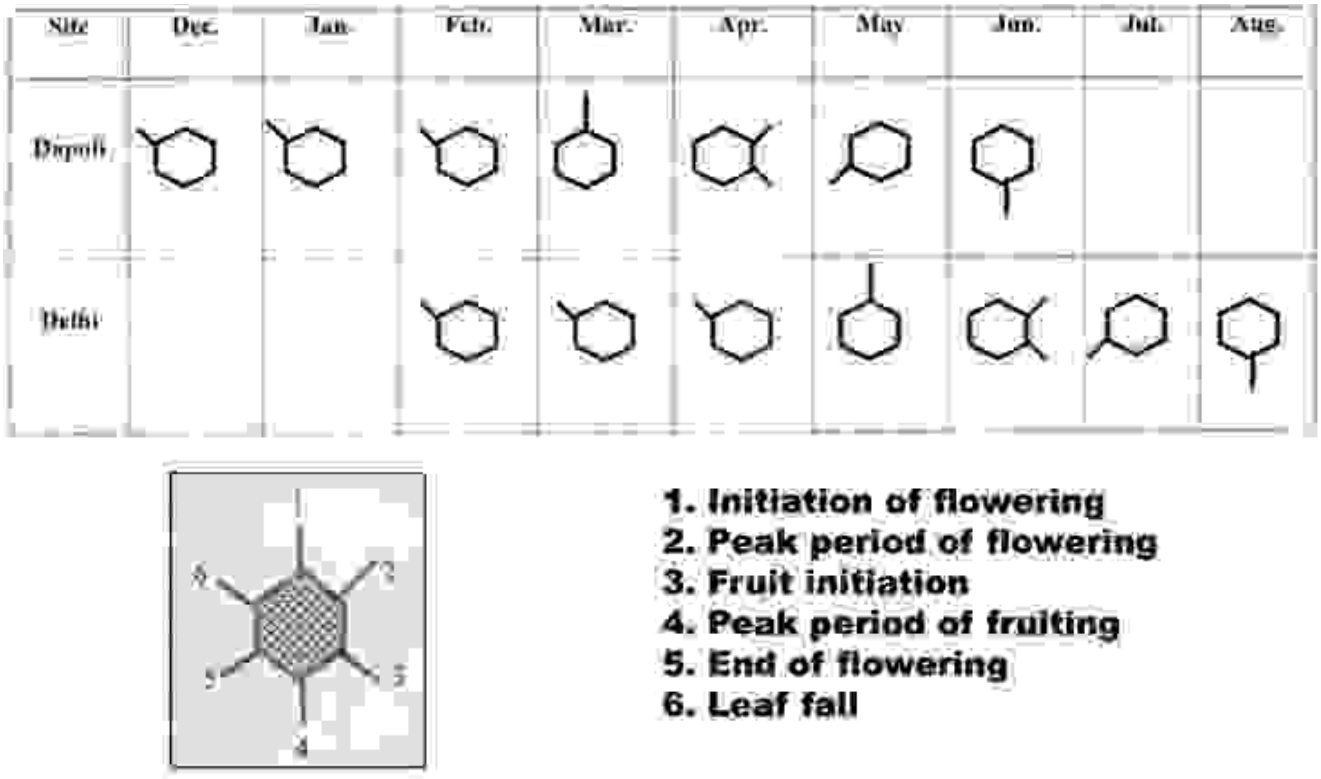

Fig. 1 — *Terminalia chebula*; Phenogram showing comparison of vegetative and reproductive phases at Dapoli and Delhi

relative humidity (RH) of the two regions. Temperature in Western Ghats during March-April was 25-30°C, and in Delhi during May-July it was 40-45°C. In both the sites flowering occurred before monsoon, when temperature was high and relative humidity (RH) was low. In both the locations, the trees bloom *en masse* continuously for about one month period. The short flowering season of *T. chebula* was compensated for by its massive blooming. According to Frankie *et al.* (1983a), most tropical tree species that flower in the dry season are mass blooming. Abundant flowering for a short period is known to encourage active foraging by pollinators, resulting in increased competition between pollinators and a consequent increase in the degree of outcrossing. Flowering in a tree was not synchronous. It started from the canopy, later it extended downward to the lower branches. Fruit maturation was a slow and gradual process extending over 6-7 months. At the end of reproductive cycle, the tree was completely leafless while the mature fruits were still attached to the branches.

Floral Biology—The inflorescence was of racemose type on which sessile flowers were present in acropetal succession. The flower was pale yellow, bisexual, actinomorphic, epigynous and apetalous, having a whorl of sepals. A large number of small flowers arranged in dense inflorescence (spike) appeared attractive. Flower was glabrous outside and covered by hairs inside. Sepals were five, fused, campanulate, arranged in valvate aestivation. Bracts were present at the bud stage but were deciduous. Stamens were generally ten in number, arranged in two whorls of five each. Anthers were present on long filaments, bilobed, dorsifixed and extrorse. Ovary was monocarpellary, unilocular and inferior with two pendulous anatropous ovules of which only one developed into seed. Ovary was covered with numerous hairs. Style was long and erect. Stigma was pale yellow when young but became reddish at the time of receptivity. Five bilobed nectaries were present at the base of style amidst tufts of long white hairs. The average maximum length of inflorescence was 8.0cm at Dapoli and 11.2 cm in Delhi. The number of flowers per inflorescence varied significantly at Dapoli and Delhi. At Dapoli each spike at maturity consisted of 80-120 flowers, whereas in Delhi the number was 150-200. Length of stamens and style also varied in populations of Dapoli and Delhi. The length of stamens and style was longer in the flowers collected from Dapoli as compared to Delhi. Variations in length of sepals, petals, stamens and style have been observed (Table 1).

Table 1 — *Terminalia chebula* : Dimensions of floral parts (mm) at Dapoli and Delhi

Site	Dapoli	Delhi
Length of the flower (mm)	7.9±0.42	6.8±0.52
Length of sepal (mm)	3.5±0.27	2.8±0.56
Length of stamen (mm)	6.0±0.45	5.1±0.32
Length of style (mm)	6.2±0.67	5.3±0.56

(Values are mean ± standard deviation of 50 replicates)

Anthesis and Anther Dehiscence—At Dapoli, anthesis started at 00.00h and continued up to 03.30h in the night with a maximum frequency at 01.00-02.00h. During anthesis period, temperature at Dapoli was 20-22°C and RH 70-75%. At Delhi, anthesis started at 23.30h and continued till 04.00h. The maximum flowers opened between 02.00 and 03.00h when temperature and relative humidity were 35-40°C and 42-45% respectively. Temperature and relative humidity affect the rate of anthesis. After anthesis, flower colour changed from green to light yellow. Bees were attracted by light yellow colour of the flowers (Weiss 1995). Therefore, this change in the floral colour was associated with the increase in pollinator efficiency.

During anthesis, the style emerged out before the emergence of the anthers. It projected out two days before the calyx expanded. On the second day, it increased in size from 2 to 3mm and at this stage the stigma became receptive. Thus, reproductive period can be divided in two phases: (1) female phase, when the stigma was receptive and anthers were not exposed; (2) bisexual phase, when anthers dehisced successively and stigma continued to be receptive. Such a type of dichogamous mechanism, where stigma became receptive before the anther dehiscence and continued to be receptive as long as anther dehiscence lasted, was considered to be incomplete protogyny. Similar mechanism has been observed in *Bulnesia retama* (Debandi *et al.* 2002) and in *Larrea nitida* and *L.*

tridentata where the stigma emerged out before the anthers and continued to be receptive during anther dehiscence (Rossi *et al.* 1999). A few other species of *Terminalia* have been earlier reported to show dichogmaous mechanism. Of these, *T. amazonia* (Flores E 1994) and *T. pallida* show protogyny (Solomon Raju *et al* 2012), and *T. tomentosa* shows protandry (Atluri & Rao 2000). In *T. chebula* the receptive stigma has an opportunity to receive outcrossing pollen first. This strategy keeps the stigma safe for some time from self-pollen, but delayed self-pollination can occur if cross-pollination fails. Style projection before the unfolding of the calyx is an excellent mechanism in *T. chebula* to protect the stigma from getting overloaded with auto pollen deposition, thus favouring outcrossing.

When counted from the time of style emergence, flower life lasted for 5-6 days. As the flower opened, all stamens did not extrude simultaneously, but came out one by one. On the third day of anthesis, the stamens of outer whorl emerged, followed by those of the inner whorl on next day (Figs. 2A & B). Likewise, the dehiscence was asynchronous. Anthers dehisced as these emerged out. This asynchrony kept pollen getting dispersed for a longer duration, thus attracting the pollinators and extending the period of time for visitors to pollinate flowers. Asynchrony in anther emergence and dehiscence was advantageous for the species since it not only made the pollen available for longer period but also attracted pollinators for a longer duration, thereby boosting the outbreeding potential of the species (Wyatt 1982). Asynchronous anther dehiscence has been observed in *Foeniculum vulgare* in which stamens extruded one by one, so that male phase got extended and the opportunity for insect visitors to collect pollen was also enhanced (Koul *et al.* 1996).

Pollen grains were released through longitudinal slits in the anther. A unique feature of this plant was the presence of calcium oxalate crystals in anther locule (Fig. 2C). At maturity crystals were present near stomium, which later on scattered in anther locule (Fig. 2D).These crystals were released with the pollen grains during anther dehiscence, but such crystals were not observed on stigma surface during pollen germination. According to Horner & Wagner (1992), such crystals when present near stomium helped in anther dehiscence. In *Philodendron melionii* and *P. ornatum* presence of calcium oxalate crystals on stigmatic surface helped in pollen germination and therefore increased the reproductive efficiency (Barabe & Lacroix 2000). In *Petunia* calcium oxalate crystals supply Ca++ ions necessary for pollen germination (Iwano *et al.* 2004). In *T. chebula* calcium oxalate crystals have not been observed on stigma surface. Therefore, it seems that these crystals help only in anther dehiscence and have no further role in pollen-pistil interaction.

Pollen grains showed 3-5 colpi and pores, with smooth exine. Pollen grains had tendency to make clumps on surface of anther wall, which indicated adaptation for insect pollination. Viability of pollen from freshly dehisced anthers was tested through FDA test. Pollen viability decreased with the increase in the number of days after dehiscence. Pollen grains collected from Dapoli showed 92.9% viability at the time of anther dehiscence and those collected from Delhi showed 87.4% viability. Viability dropped in five days after anther dehiscence under natural conditions. In *T. paniculata* pollen viability at the time of dehiscence was 92% and pollen grains lost their viability after 24 hours of anther dehiscence (Thangaraja & Ganesan 2008), whereas in *T. arjuna* 95% pollen grains were viable at the time of anther dehiscence but lost their viability after 8 hours (Chauhan *et al.* 2008). At the time of anther dehiscence pollen grains were at 2-celled stage (Fig. 2E).

Ovary was inferior with two ovules but only one of these developed into mature seed. Ovules were pendulous, anatropous, bitegmic with long funiculus. Ovary was surrounded by large number of trichomes at the base.

Pollination Biology—Five bilobed floral nectaries were present at the base of the style, which were concealed with long and white hairs. Pollinators came to collect the nectar and during this process they helped in carrying pollen grains from anther to stigma. Experiments conducted by bagging of flowers with mosquito nets to prevent insects from visiting the flowers revealed that flowers that received no insects did not show any fruit formation. This showed that external agents were required for pollination. Therefore, mode of pollination was entomophillic. Srivastava (1993) also studied

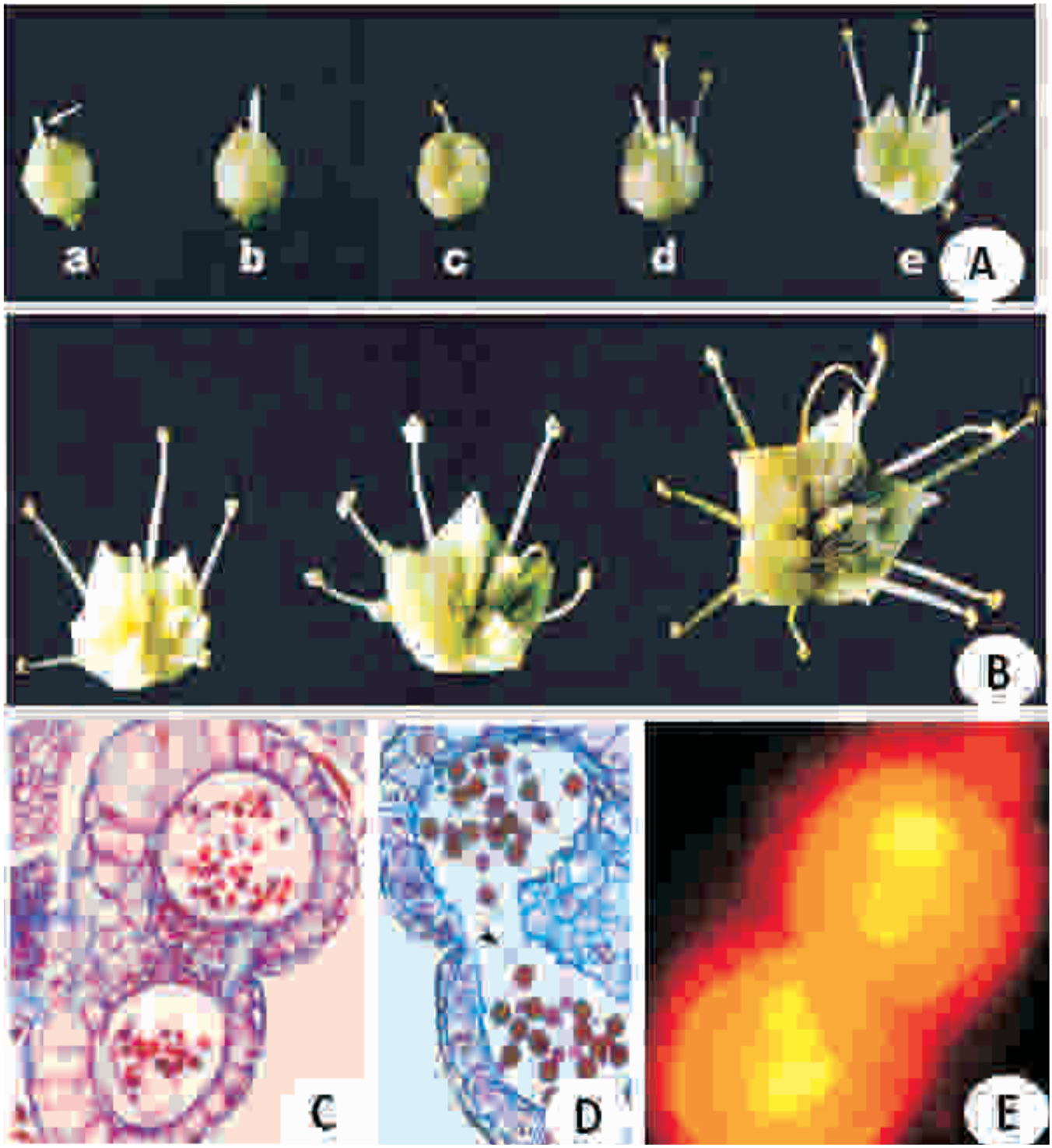

Fig. 2 — *Terminalia chebula.* **A:** Flowers (a) and (b) showing emergence of style (arrow) on first and second day of anthesis. Flowers (c), (d) and (e) showing asynchronous emergence of stamens of outer whorl, **B:** Flowers showing asynchronous emergence of stamens of inner whorl, **C:** Transverse section of anther showing crystals near stomium (arrow), **D:** Transverse section of anther lobe before dehiscence showing abundant pollen grains and scattered crystals (arrow head) near stomium, **E:** Pollen grains stained with ethidium bromide showing two nuclei.

pollination mechanism in four species of *Terminalia* (*T. arjuna*, *T. chebula*, *T. tomentosa* and *T. paniculata*) and reported that the genus is entomophilous. Hymenopterans, particularly *Apis dorsata* and *Apis florea*, play an important role in pollination.

The number of insects visiting the flower was recorded starting from 06.00h to 18.00h over a period for seven days. In Dapoli, foraging activity started at 07.00h, and in Delhi it started at 06.30h. Maximum insect activity was between 09.00h and 11.30h, and then there was a sudden decline in the number of insect visitors from 12.00h to 16.30h because of rise in temperature. However, activity of insects increased again around 17.00h and continued up to 18.00h. Insect activity was more pronounced on sunny days or in the sunlit areas of the canopy. Cloudiness was found to reduce the number of insects visiting the flowers. All insect pollinators were more active between 09.00h and 11.30h.

A preliminary survey was made to list all insects that visited the trees at Dapoli and Delhi. Pollination studies have indicated that there was a variation in the species of pollinators visiting the flowers at Dapoli and Delhi. The different insect species that visited the populations of *T. chebula* are listed in Table 2. *Camponotus* sp. and *Polistes hebraeus* were common in both places. Other insects such as *Euchromia polymena*, *Lucilia sericata* and *Spindasis vulcanus* which pollinated flowers of *T. chebula* growing at Dapoli were absent from the trees growing in Delhi (Figs. 3A-F). Similarly, *Apis dorsata* and *Vespa orientalis* which were major pollinators of *T. chebula* growing in Delhi were not seen on any of the flowers at Dapoli (Figs. 4A-F). Some of the pollinators such as *Danaus chrysippus*, *Tirumala limniace*, *Graphium nomius*, *Phalanta phalantha*, *Apis dorsata*, *Apis florae*, *Apis cerana indica* and *Vespa orientalis* in *T. chebula* at both Dapoli and Delhi (present study) are also the pollinators of *T. pallida* in Eastern Ghats of India (Solomon Raju *et al.* 2012).

Morphological floral traits determine the type of pollinating agents the plant requires for its successful propagation. It is observed that flowers at Dapoli were mostly visited by butterflies, whereas in Delhi bees were more frequent visitors. The flowers of *T. chebula* growing at Dapoli had long style and long stamens which favoured the visits of butterflies. As flowers at Dapoli have longer styles and stamens, these are likely to facilitate greater contact with the body parts of butterflies with long legs. During their visits, anthers touched the thorax of butterflies where the pollen grains got adhered. When the same butterfly visited another flower, the exposed stigmatic surface came in contact with the thorax of the butterfly having pollen grains. In Delhi, where the flowers have shorter style and stamens, small sized bees constituted the effective pollinators. In *Acacia terminalis*, long-styled flowers are visited by birds and short-styled flowers are visited by bees (Kenrick *et al.* 1987). As the number of flowers per inflorescence is more in Delhi, bees spend more time in foraging the flowers within the same inflorescence. As compared to other insects in Delhi, bees were considered the most efficient pollinators on the basis of their pollen pick up and foraging rate.

In *T. chebula*, bees foraged at almost all levels in the canopy of the trees but butterflies prefered to forage only at the apex of the canopy. As flowers were arranged in acropetal manner, insects foraged open flowers and moved from base to apex. Therefore, some young flowers, which had their style and stigma exposed before anthers, received geitono or xeno pollen first, thus favouring outcrossing. The crawling movement of black ants (*Camponotus* sp.) within the inflorescence caused self-pollination.

Breeding Behaviour—Experiments were designed to study the breeding system of the trees growing at Dapoli and Delhi. The results of experiments in *T. chebula* indicated that it has facultative xenogamous breeding system. High pollen:ovule ratio also indicated that the species is facultative xenogamous (Cruden 1977).

Autogamy did not take place without the pollen mediation by the flower visitors. When the flowers were bagged before anther dehiscence fruit set was zero. This showed that external agents were required even for self-pollination. It was because the contact between the anthers and stigma within the same flower did not take place as the anthers and stigma were spatially separated. After emerging from the flower, anthers moved towards periphery creating a larger distance between anther and stigma. Similar mechanism has also been observed in *T. arjuna* where self- as well as cross-pollination are

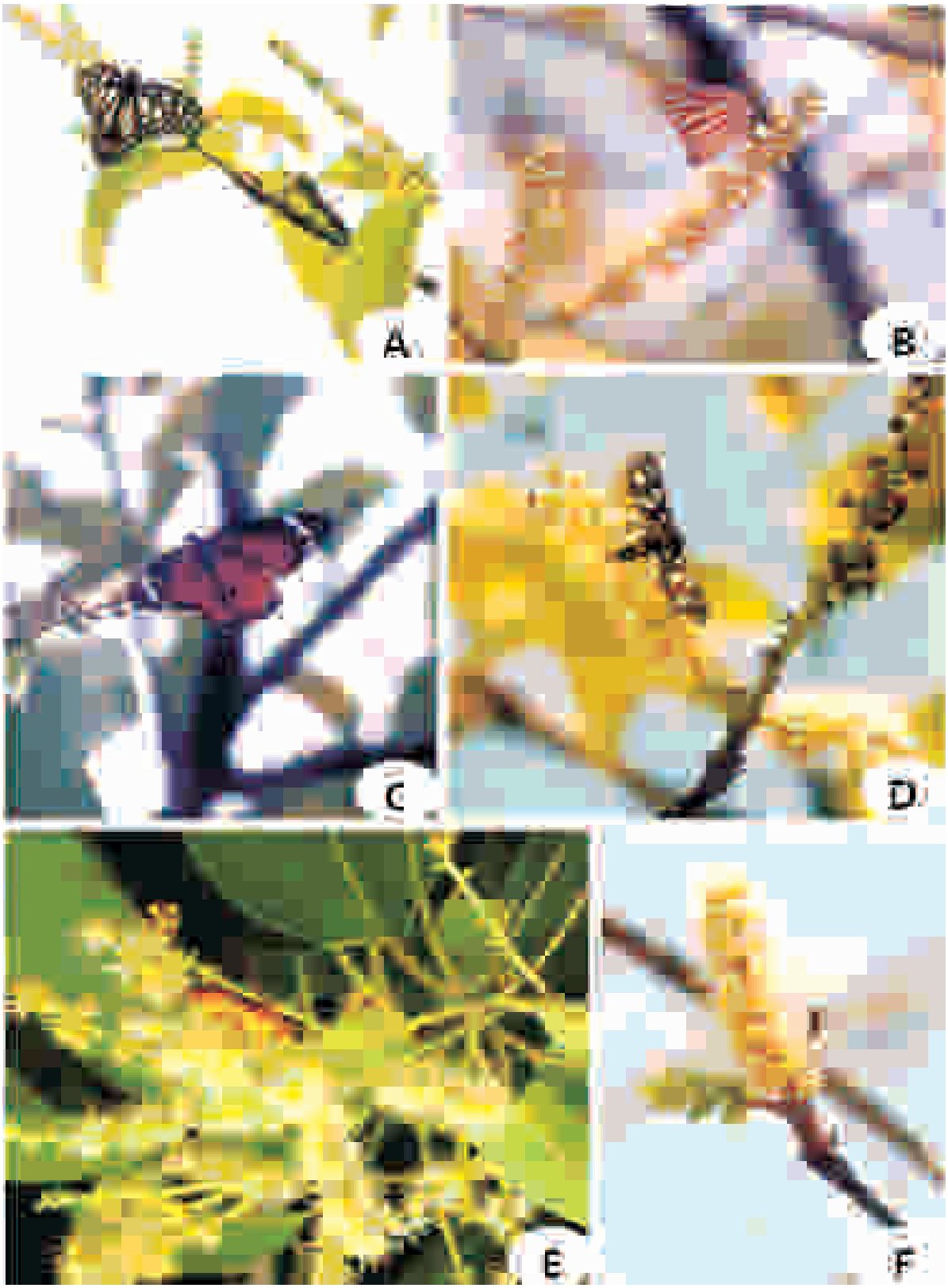

Fig. 3 — *Terminalia chebula:* Plant-pollinator interaction in Dapoli. **A:** *Tirumala limnaceae,* **B:** *Spindasis vulcanus,* **C:** *Danaus chrysippus,* **D:** *Euchromia polymena,* **E:** *Polistes hebraeus,* **F:** *Camponotus sp.*

Table 2 — *Terminalia chebula*: Insect visitors at Dapoli and Delhi

Order and family	Scientific Name	Common Name	Territory	Dapoli	Delhi
Lepidoptera, Danaidae	*Danaus chrysippus*	Tiger butterfly	Canopy	+	-
Lepidoptera, Nymphalidae	*Tirumala limniace*	Blue tiger	Canopy	+	-
Lepidoptera, Lycaenidae	*Spindasis vulcanus*	Blue butterfly	Canopy	+	-
Lepidoptera, Paplionidae	*Graphium nomius*	Spot swordtail	Canopy	-	+
Lepidoptera, Pieridae	*Pieris brassicae*	Small white	Canopy	-	+
Lepidoptera, Nymphalidae	**Phalanta phalantha*	Common leopard	Canopy	+	-
Lepidoptera, Lymantriidae	**Lymantria* spp.	-	Canopy	+	-
Lepidoptera, Ctenuchidae	*Euchromia polymena*	-	Lower branches	+	-
Hymenoptera, Apidae	*Apis dorsata*	Giant honeybee	Canopy, lower branches	-	+
Hymenoptera, Apidae	*Apis florae*	Dwarf honeybee	Lower branches	+	-
Hymenoptera, Apidae	*Apis cerana indica*	Indian honey bee	Canopy, lower branches	+	-
Hymenoptera, Vespidae	*Vespa orientalis*	Oriental hornet	Lower branches	-	+
Hymenoptera, Vespidae	*Polistes hebraeus*	Yellow wasp	Canopy, lower branches	+	+
Hymenoptera, Sphecidae	**Tachytes* spp.	-	Lower branches	+	-
Coeloptera, Cerambycidae	*Nupserha* spp.	-	Lower branches	-	+
Hemiptera, Pyrrhocoridae	**Dysdercus cingulatus*	-	Lower branches	+	-
Diptera, Syrphidae	*Eristalinus arvorum*	Hover fly	Lower branches	-	+
Diptera, Calliphoridae	*Lucilia sericata*	Green bottle fly	Lower branches	+	-
Hymenoptera, Formidiae	*Camponotus* spp.	Black ant	Lower branches	+	+

(+) presence and (–) absence of pollinators,*pollinators rarely seen

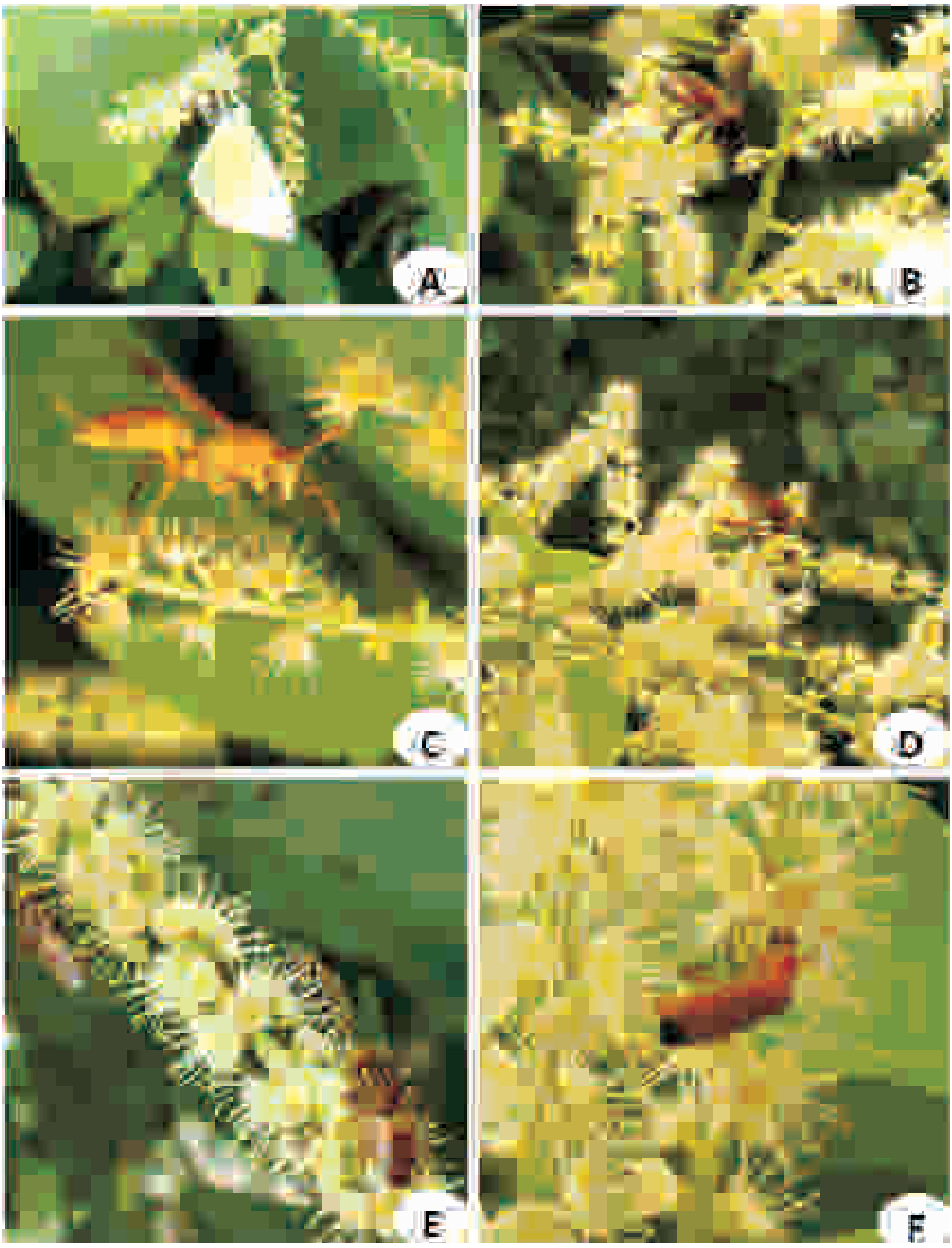

Fig. 4 — *Terminalia chebula:* Plant-pollinator interaction in Delhi. **A:** *Pieris brassicae,* **B:** *Apis dorsata,* **C:** *Polistes hebraeus,* **D:** *Vespa orientalis,* **E:** *Eristalinus arvorum,* **F:** *Nupserha sp.*

dependent on the flower visitors (Chauhan *et al.* 2008). In flowers which rely on insects for cross-pollination, the anthers and stigma are separated by a small gap to allow the passage of insects (Proctor *et al.* 1996).

In *T. chebula* flowers were small, bisexual and light yellow. In Dapoli, when inflorescences were manually cross-pollinated, 80-90 per cent fruit set was observed. To check the presence or absence of apomixis, flowers were emasculated a day before anther dehiscence and then bagged. No fruit set was observed after 15 days indicating the absence of apomixis (Table 3). Apomixis has been reported in *T. catappa* which is andromonoecious, as inflorescence bears bisexual flowers at the base and staminate ones above (Atluri *et al.* 2003). Flowers were self- as well as cross-pollinated in *T. chebula* but most of the fruits resulting from autogamous and geitonogamous pollination fell off and xenogamous fruits were retained till maturity in both Dapoli and Delhi. This strategy is favoured by plants to allocate maximum resources to fruits resulting from cross-pollination (Radhamani *et al.* 1993). *T. arjuna* also sheds most of its autogamous and geitonogamous fruits and only the xenogamous fruits are retained till maturity (Chauhan *et al.* 2008). In open pollination, the average fruit set was 8-10% in trees growing at Dapoli, whereas in Delhi the fruit set was only 2-4%. In *T. tomentosa* and *T. pallida* fruit set was 2% and 6% respectively (Atluri & Rao, 2000, Solomon Raju *et al.* 2012), whereas in *T. arjuna* natural fruit set was 48% (Chauhan *et al.* 2008). Trees growing at Delhi are sparsely distributed. Length of inflorescence and number of flowers per inflorescence were more in trees growing at Delhi. Bees spend more time in foraging within the inflorescence, thus increasing the possibility of self-pollination which may be responsible for early dropping of fruits. Trees growing at Dapoli were closely distributed. Foraging time of pollinators within the same inflorescence was less as compared to the trees growing in Delhi, which could increase cross-pollination. The effects of fragmentation on pollinator diversity and foraging behaviour have important implications for both the reproductive success and the mating systems of flowering plants. As resources available to pollinators in fragmented landscapes are less abundant and far, many pollinators invest more time in foraging within the same plant or flower, increasing the level of selfing (Cascante *et al.* 2002, Fuchs *et al.* 2003). In *T. chebula* natural fruit set was low, compared to high flower production. The tree, being self-compatible, produces fruits through both self- and cross-pollination, initiating more fruit production but fewer reaching maturity. Similar condition has been reported in *Pterocarpus santalinus*, where number of fruits formed is much less as compared to flowers (Rao & Raju 2002). Most of the endemic and endangered plant species have been reported to be self-compatible and this selfing ability is expected to be a

Table 3- *Terminalia chebula*: Fruit set through manual pollination at Dapoli

Mode of Pollination	Year 2004			Year 2005			Year 2006		
	No. of flowers pollinated	No. of fruits set	Per cent fruit set (%)	No. of flowers pollinated	No. of fruits set	Per cent fruit set (%)	No. of flowers pollinated	No. of fruits set	Per cent fruit set (%)
Natural autogamy (bagged flowers)	100	0	0	100	0	0	100	0	0
Manipulated autogamy	100	20	20	100	16	16	100	18	18
Geitonogamy	100	25	25	100	30	30	100	22	22
Xenogamy	100	90	90	100	87	87	100	85	85
Open pollination	1927	205	10.6	2014	162	8.04	1650	135	8.1
Apomixis	100	0	0	100	0	0	100	0	0

fail-safe strategy to produce fruits when there is a lack of pollinators (Neel 2002). This breeding system is also advantageous for *T. chebula* because it ensures continued survival of tree. However, self-pollination can be responsible for inbreeding depression observed in several tree species (Thakur & Bhatnagar 2013).

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