

Pollen production and release in *Mesua ferrea* Linn. (Guttiferae): a spatio-temporal pattern

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Received: 28 November 2015 / Accepted: 1 June 2016
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Abstract Based on a five-year study of pollen production and release in two different natural populations of *Mesua ferrea* from Indo-Burma region of Northeast India, we determined that pollen output follows a spatio-temporal pattern. Pollen productivity determinations considered various sources of variability, including the number of flowers per branch, flowers per tree, anthers per tree and pollen grains per tree. Each of these parameters revealed significant year-to-year and population effects. Anthesis follows a forenoon pattern, whereas anther dehiscence pursues the diurnal pattern. The former was significantly correlated with the timing of floral visitation and pollen deposition on stigmas. The latter, however, had significant relationship with the deposition of pollen grains on microscopic slides. The *Apis* and *Xylocopa* bees are the efficient pollinators to achieve the reproductive success in *M. ferrea*. Annual production of pollen per tree varied from averages of $1.07 \pm 0.10 \times 10^{10}$ and $3.24 \pm 0.16 \times 10^{10}$ in years of low production, with alternate high years,

producing $3.85 \pm 0.34 \times 10^{10}$ and $8.22 \pm 0.76 \times 10^{10}$ pollen grains per tree.

Keywords Anthesis · Pollination · Pollen production · Pollinators · Temporal pattern

1 Introduction

Mesua ferrea Linn. an evergreen tree belongs to family Guttiferae is a highly valuable medicinal tree species which occurs naturally in the Northeast and southern part of India. It also grows naturally in the tropical regions of Cambodia, Malaysia, Myanmar, Philippines, Singapore, Sri Lanka, Thailand and Vietnam. The species is used for the treatment of variety of diseases in Ayurveda, Siddha and Unani systems of medicine. It is also considered as Nagakesara in Ayurveda, Sirunagappo in Siddha, Naarmushk in Unani and Cobras Saffron and iron wood tree in English. Bark, leaves, flower and fruits are reported to have medicinal properties. The flowers are most important part used for the treatments of various ailments. The species is used as a constituent of about 11 compounds of Unani formulations. Pharmacologically, the species is reported to contain several drugs properties, i.e. anti-asthmatic (Bhide et al. 1977), oestrogenic and progestational (Meherji et al. 1978), anti-inflammatory (Gopalakrishnan et al. 1980), anthelmintic (Kakrani et al. 1984), anti-spasmodic

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(Prasad et al. 1999), anti-tumour (Palani et al. 1999), antibacterial (Mazumder et al. 2004), anti-cancer (Keawsa-ard and Kongtaweelert 2012), anti-microbial (Chanda et al. 2013), antioxidant and immunomodulatory (Chahar et al. 2012).

The study on pollen production and pollination in *M. ferrea* is completely lacking so far. Therefore, the current study was aimed to understand the reproductive phenological attributes along with pollination, pollinator frequency, pollen concentration in the air, pollen production by individual tree and their temporal and spatial variation in *M. ferrea*. The long-term subsistence of species is dependent on the reproductive capacity to the different environment so that it can adapt the environmental changes which would further be maintained by improving species through the interracial breeding programme. Pattern of racial variation reflect the responses of species to evolutionary forces so that the species may continue to evolve in future. Therefore, the studies of the pattern of variation in reproductive efforts are of immense practical significance to understand the evolutionary bases of any species.

2 Materials and methods

2.1 Study site

The study was undertaken during five successive flowering seasons of 2006, 2007, 2008, 2009 and 2010 at two different locations, that is: (i) Bethlehem Vengthlang and (ii) Tanhril (near Mizoram University Campus on the way to Aizawl city), in the district Aizawl, Mizoram, the north-eastern hill region (NEH) of India. Bethlehem Vengthlang is situated at an altitude of 900 m asl. with 23° 43' N latitudes and 92° 43' E longitudes, whereas Tanhril is located at 750 m asl which lies in between 23° 37' N latitudes and 92° 39' E longitudes. Bethlehem is comparatively cooler location than the Tanhril. Five trees in each location were selected randomly for studying each trait, i.e. floral phenology, pollinator's frequency, pollen production and pollination. The selected trees were located more than 100 m apart from each other so that they can represent the entire population. The selected trees were marked with the yellow paint so that the same trees could be followed for another year's observations.

2.2 Floral phenology

Floral phenological observations were recorded on the selected individuals on both locations in terms of timing of floral bud initiation, timing of first flowering, pattern of anthesis, anther dehiscence, duration of flowering, end of flowering, fruit maturity and seed dispersal by visual observation on weekly and daily basis during flowering phase and monthly basis during fruiting phase.

2.3 Flower and pollen production

Production of flower was determined on the five trees selected at each location. The flower of *M. ferrea* grows solitary on the dense crown; therefore, the production of flower per tree was estimated by counting the total number of branches that bear flowers per tree, and then the number of flower-bearing sub-branches was counted on five randomly chosen branches on the tree crown. Furthermore, the number of flower per sub-branch was counted on twenty different sub-branches of each individual selected randomly on the crown. Later, 25 flowers from every individual tree were harvested, and the number of stamens was counted manually. The harvested flowers were also used to measure other floral characteristics viz. number of sepals, petals, flower diameter, style length and ovule numbers. The ovule number was directly obtained from dissection of ovaries under a stereoscopic microscope. The total number of flowers per tree was calculated by multiplying number of flower per sub-branch by the number of flowered sub-branches per branch by the number of flowered branches per tree. The estimated number of flower per tree was multiplied by the average number of anthers per flower, which was finally multiplied by the average number of pollen grains per anther. The production of pollen grains per anther was counted from ten randomly selected flower buds. From each flower bud, one anther was taken and transferred to a known volume of 50 % glycerol in a test tube and macerated with glass rod. Further, a sample of known volume was placed in microscopic slides, and the pollen grains were counted under the binocular microscope. The design was based on the method used by Tormo Molina et al. (1996). The counting of pollen per anther was also done by placing the anther directly on the microscopic slides, crushed with glass

rod, and a small drop of 50 % glycerol was added to disperse the pollen grains equally to some fixed area on the slide and counted under microscope. The two methods of counting were used to reduce the chance of error, and the average value of both the methods was used ($n = 10 + 10 = 20$) for number of pollen grains per anther.

2.4 Flower pollinators

The pollinators and their frequency were determined by counting of the number of visits by the insect species on all the five chosen trees during peak time of flowering. Observations were made at distances of up to 5 m. The study period covered the 15 days of peak flowering season after every alternate day in each location. Between 15 and 20 flowers were observed simultaneously and recorded for the number of visits by the insect species to the open flowers. For each visit, the duration, contact with the reproductive parts and interactions with other visitors were recorded. In each population, the tree was observed over the course of the whole day between 0500 and 1700 h in 6 observation blocks each starting at the 2 h, i.e. between 0500 and 0700, 0700–0900, 0900–1100. The each observation blocks was randomly distributed over the trees and the course of the day. The sustainable distribution of each observation block was done over the trees within the population during the course of the study so that the every tree is monitored in each observation block. The frequency of pollinators was assessed in terms of visits/flower/hour. Only the effective pollinators' and their visitation rates were monitored, and *Apis* and *Xylocopa* bees are the main pollinators recorded for this species.

2.5 Airborne pollen deposition and deposition on the stigma

Pollen deposition in the air and on to the stigma was done by trapping of pollen grains under two conditions, that is: (i) pollen deposition on microscopic slides and (ii) landing of pollen grains on to the stigma at different time intervals of the day. The first experiment was done by exposing jelly-coated microscopic slides fastened horizontally to the top of a bamboo pole of 3 m height. The slides were fixed all around the vicinity of a tree crown. Exposure of slides

at this height gives an accurate estimate of pollen release in the air, particularly for entomophilous species. Exposure of slides was done on five different trees. The slides were placed at different time periods from dawn to dusk, i.e. 0400, 0600, 0800, 1000, 1200, 1400, 1600 and 1800 h for three successive days during the peak flowering time. The slides were replaced after every 2 h interval. The number of pollen grains per slide was counted for 1 cm² under a microscope. Similarly, the stigmas of isolated (bagged) emasculated flowers were exposed to pollinators for 2 h. The flowers were emasculated during anthesis. This experiment was to ascertain the best time of pollination during the day as well as to study the emission or dispersion of pollen grains in the air. The flowers were removed after every 2 h and placed in plastic jars with cotton wadding and saturated with formalin-aceto-alcohol. Later, twenty stigmas were mounted on glass slides and examined microscopically for the number of deposited pollen grains as per Ornduff (1975).

2.6 Fruit set

Fruit setting following open pollination was also recorded on five selected individuals in each location. This was done by choosing ten sub-branches in each tree and was flagged. The number of flowers in different selected sub-branches was counted, and the observations on fruit setting were made in September after five to six months of pollination by counting the number of fruit produced by a sub-branch and subsequently by ten sub-branches in each tree. Fruit setting was calculated by dividing the average number of fruits per sub-branch by the average number of flowers per sub-branch at pollination.

2.7 Statistical analysis

The effect of time period (years) and populations on number of flowers per tree, pollen grains per anther, pollen grains per flower, pollen grains per tree and fruit set were analysed using ANOVA. Years and populations were examined as fixed effects. The transformation of the values to log was applied in order to improve normality of residuals and to reduce heteroscedasticity (Sokal and Rohlf 1995). ANOVA was performed using the MS Excel package.

3 Results

The floral display of *M. ferrea* includes 4 sepals and petals with the average length, and width of petals was 4.1 and 3.2 cm, respectively, that attained a diameter of 7.7 cm of the flower. The phenological phases of the flowers varied significantly from one year to the next and also from one population to another. The date of floral bud initiation in the year 2008 was 8 March and 28 March at Tanhril and Bethlehem, respectively, which was 20 February and 6 March, respectively, in the year 2009. Beginning of anthesis at Tanhril and Bethlehem locations occurred on 23 March and 8 April in the year 2008 and 4 and 15 March during 2009, respectively. Blooming is asynchronous within and between the individuals in a population. Flowering duration lasts up to one and half month from the date of anthesis that also varied spatially and temporally. The flowering period at both locations in the year 2008 and 2009 was 30 and 44 days, respectively, at Bethlehem and 26 and 32 days, respectively, at Tanhril location. It was interesting to note that about 30 per cent individuals in a population at Bethlehem location occurred flowering during second week of July to the end of August. The individuals which flowered in July–August during 2008 also flowered at same time in the year 2009. This phenomenon was not observed at Tanhril location. The flower once opened lasts up to two and half days at warmer location (Tanhril) and three and half days at cooler location (Bethlehem). The stigma was observed receptive at the time of anthesis and the anther dehiscence started 1 h after anthesis. Therefore, the flowers are slightly protogynous. The stigmas remained receptive up to two days. There was overlapping between stigma receptivity and anther dehiscence.

Apis cerana (honey bees) and *Xylocopa latipes* (carpenter bees) have been observed the efficient pollinators in *Mesua ferrea*. The visitation rates differed significantly ($p < 0.0001$) with the insect species and also varied significantly ($p < 0.001$) from one population to another. The average visitation rates for *Apis* and *Xylocopa* bees were 3.91 ± 1.28 visits/flower/hour and 1.43 ± 0.59 visits/flower/hour, respectively, for Bethlehem population and 2.67 ± 1.08 visits/flower/hour and 1.02 ± 0.48 visits/flower/hour, respectively, for Tanhril population. The peak pollinator frequency at both populations was recorded between 0700 and 0900 h of the day.

Visitation rates of both pollinators differed among individuals in the population which varied from 0.66 to 7.14 visits/flower/hour for *Apis* bee and 0.26–2.8 visits/flower/hour for *Xylocopa* bees at Bethlehem population and 0.86–6.24 visits/flower/hour for *Apis* bee and 0.16–2.0 visits/flower/hour for *Xylocopa* bees at Tanhril population (Fig. 1a, b).

Pattern of landing of airborne pollen grains on exposed microscopic slides and on to the stigma was different, and the relationship was not significant ($P < 0.3260$). The former was significantly ($P < 0.001$) related to the anther dehiscence, and the later was highly significantly correlated ($P < 0.0001$) with the time of pollinators visitations and also coincided with the time of anthesis. The highest pollen load of 58.24 pollen grains per stigma and of 38.56 pollen grains per cm^2 on exposed slides was recorded between 0800 and 1000 h and 1200 and 1400 h of the day, respectively (Fig. 2).

Flowers of *M. ferrea* bear solitary on the crown and a sub-branch of a tree on an average produced 58.85 ± 2.38 flowers. A flower contains several numbers of anthers which ranges between 948 and 1202 per flower. The production of pollen grains per anther oscillated between 3204 and 4409. The average production of flower per tree in low production years (2007 and 2009) at Bethlehem and Tanhril sites was 6840 and 4104, respectively, which in the high production years (2006, 2008 and 2010) was recorded as 17,258 and 13365, respectively (Table 1). The frequency of flowering was highly variable between the sites and among the years. Years of high production (2006–2008–2010) alternates with years of low production (2007 and 2009). The analysis of pollen production per tree over five consecutive years (2006–2010) has revealed that the production of flowers per tree was about three times more at Bethlehem site and six times high at Tanhril site in the years 2008 as compared to 2009, respectively (Table 1). Similarly two times more production was observed in the year 2006 than 2007 at both the sites. There was variation in the production of flowers between the sites during leap and poor production years. Bethlehem site produced 23 and 40 per cent more flower than Tanhril site during elevated and low production years, respectively, which clearly is depicting a spatio-temporal pattern of pollen in *M. ferrea*. Additionally, each good production year in both sites was followed by a poor production year

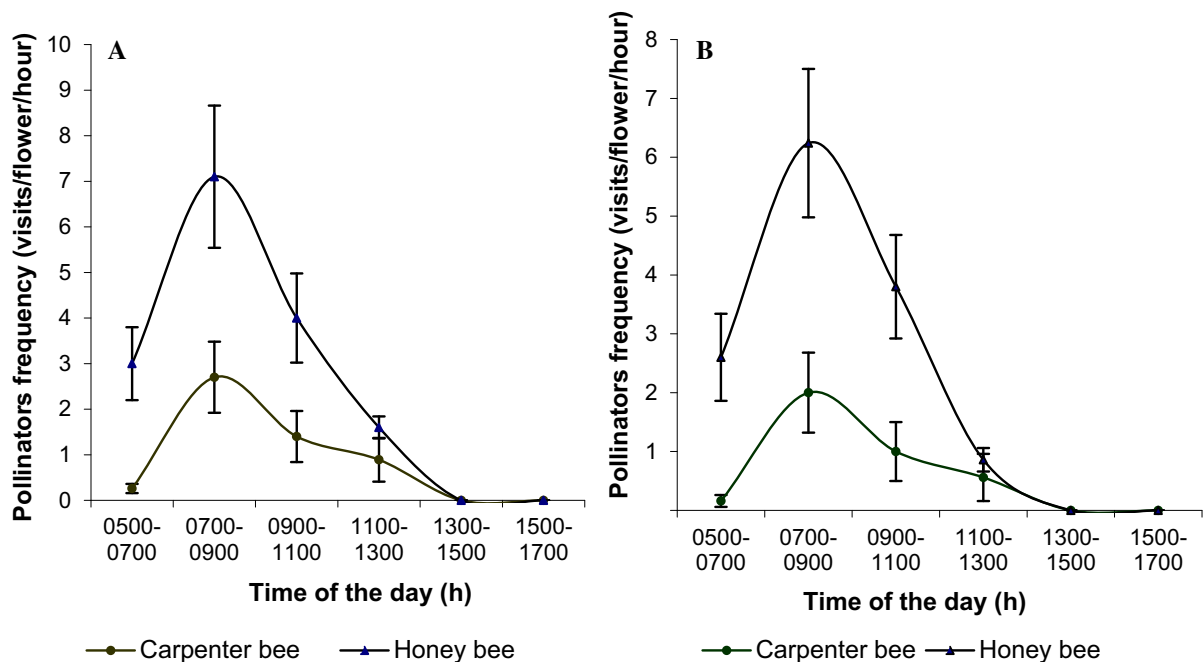


Fig. 1 Frequency of pollinators' visitations in *Mesua ferrea* with respect to the time of the day, **a** Bethlehem population and **b** Tanhril Population

obviously portraying biannual behaviour of flower and pollen production in *M. ferrea*.

The production of flower is directly proportional to the production of pollen grains per tree. As a result, the pollen yield per tree at Bethlehem and Tanhril sites during leap year was estimated as of 7.05×10^{10} and 5.15×10^{10} , respectively, which in the poor production years were 3.13×10^{10} and 1.80×10^{10} , respectively. The fruit set percentage per tree following natural pollination was recorded maximum of $74 \pm 4.54\%$ at Bethlehem site and minimum of $50.4 \pm 6.45\%$ at Tanhril site.

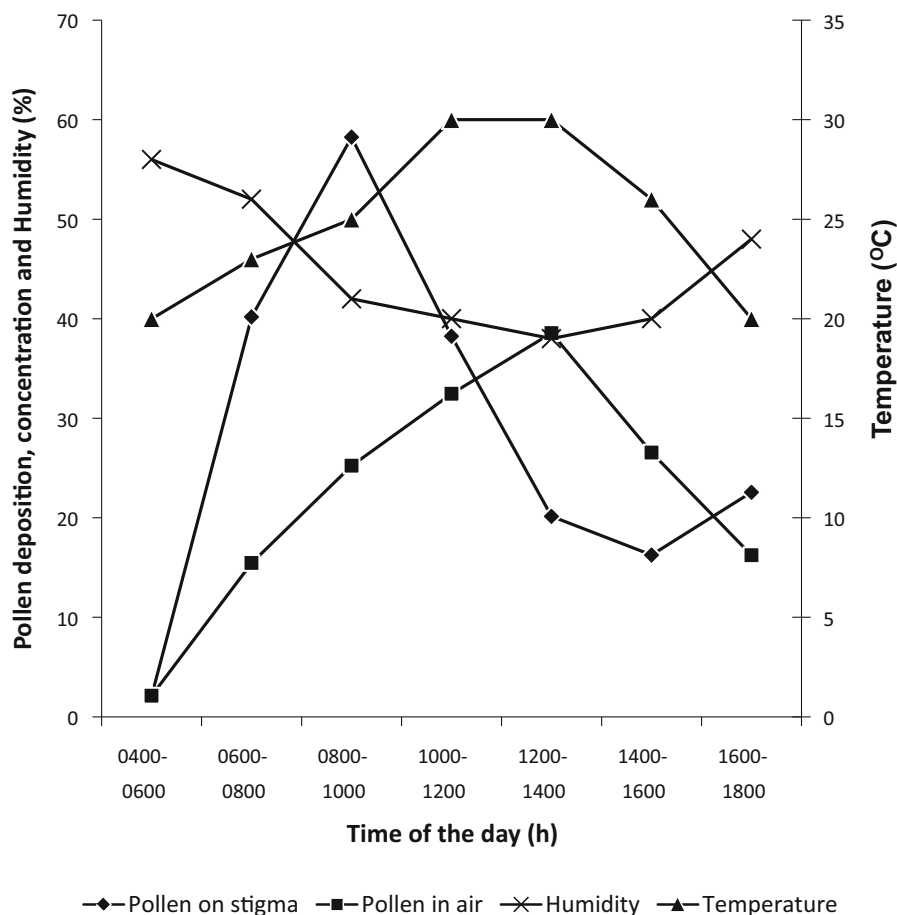
The production traits varied significantly with time and space. There was significant effect of year, population and the interaction of year $\times$ population on the production of flowers per tree ($p < 0.0001$, 0.0001 , and 0.0002 , respectively), pollen grain per tree ($p < 0.0001$, 0.0001 , and 0.0004 , respectively) and fruit set percentage per tree ($p < 0.0001$, and 0.0122 , respectively). The fruit set percentage per tree has shown non-significant effect with the interactions of year and population ($p < 0.2438$). The number of pollen grains per anther and pollen grains per flower proclaimed non-significant effect of year ($p < 0.5672$ and 0.4236 , respectively) and interaction between year

and population ($p < 0.4976$ and 0.4874 , respectively). Both traits, however, have revealed significant effect of population ($p < 0.0456$ and 0.0062 , respectively) (Table 2). The existence of statistical results further explains that the pollen number per anther and stamen number per flower were equally variable in elevated and low production years. The range of variation was narrow in terms of stamens per flower and pollen grains per anther, which depict that the level of pollen production in a particular species is a function of its genotype and the number of pollen grains per anther might be genetically fixed. However, climatic factor at distinct sites may affect the trait in addition to its genotype, which ultimately caused variation if trees are growing at different sites. There was significant positive relationship ($r = 0.90266$, $p < 0.0001$) between production of flower per tree and fruit set percentage per tree (Fig. 3).

4 Discussion

The results of floral phenology revealed that the timing of reproductive phenological attributes in *Mesua ferrea* is influenced by the environmental factors,

Fig. 2 Pollen frequency in the air and on to the stigma of *Mesua ferrea* in relation to the time of the day and weather factors (data are average of 5 days: between 15.04.2008 and 25.04.2008)



particularly the temperature. The pattern of anthesis was forenoon (6.00–11.00 h), however, anther dehiscence was diurnal. The former was significantly correlated with the timing of floral visitation and pollen deposition on stigmas. The latter, however, had significant relationship with the deposition of pollen grains on microscopic slides. The forenoon pattern of anthesis was also reported for *Kleinhovia hospita*, *Delonix regia*, *Cassia siamea*, *Aegle marmelos*, *Butea monosperma*, *Tectona grandis*, *Moringa oleifera*, *Terminalia arjuna* and *Dillenia indica* (Gregory 1973). Low level of relative humidity (RH) and high temperature accelerate anther dehiscence and high humidity and low temperature promote anthesis in *Mesua ferrea*. Following anther dehiscence, mature pollen grains were available to the insects to carry them into the receptive surfaces of stigmas, which in turn, utter the pollination success of a species and play important part for determining the genetic make-up of

populations. Though the pollen of *Mesua ferrea* was releasing into the atmosphere, but the rapport between pollen deposition on stigma and on microscopic slides was not significant; however, the significant strong relationship between pollinator visitation and pollen deposition on stigmas clearly depicts that the species is entomophilous.

The anther dehiscence is a vital occurrence that determines the successive release of pollen grains (male gamete) into the stigma of pistil through biotic and abiotic means. The anther dehiscence is an eerie process that proceeds in events of series that is: (i) dehiscence before anthesis (Examples *Eucalyptus globosus*, *Butea monosperma*, *Anthocephalus chinensis* and *Syzygium jambos*), (ii) anther dehiscence overlap with anthesis (e.g. *Aegle marmelos* and *Kleinhovia hospita*), and (iii) anther dehiscence after anthesis (e.g. *Bombax ceiba*, *Cassia fistula*, *C. siamea*, *Delonix regia*, *Dillenia indica*, *Moringa oleifera*,

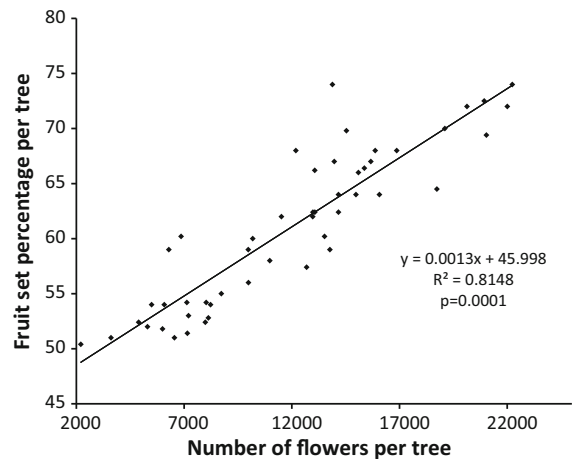
Table 1 Annual production of flower, pollen and fruit set per tree in *Mesua ferrea*

Site/ year	Tree diameter (cm)	Tree height (m)	Flowered main branches/tree	Flowered sub- branches/main branch	Flowers/sub- branch	Anthers/ flower	Pollen grains/ anther	Flowers/ tree	Pollen grains/ tree ($\times 10^{10}$)	Fruit set (%) (open pollination)
Bethlehem Venghlang										
2006	19	11	32	08 $\pm$ 0.48	62 $\pm$ 5.42	984 $\pm$ 36.56	3842 $\pm$ 362.2	15,872	6.0	62.4 $\pm$ 2.86
2007	Same trees sampled	22		06 $\pm$ 0.42	54 $\pm$ 4.23	1126 $\pm$ 48.56	4040 $\pm$ 506	7128	3.24	55 $\pm$ 3.84
2008	Same trees sampled	45		07 $\pm$ 0.82	69 $\pm$ 6.45	1084 $\pm$ 48.80	3490 $\pm$ 158.62	21,735	8.22	74 $\pm$ 4.54
2009	Same trees sampled	14		09 $\pm$ 0.60	52 $\pm$ 1.96	1128 $\pm$ 52.2	4098 $\pm$ 392	6552	3.03	52.8 $\pm$ 5.64
2010	20	14	23	11 $\pm$ 0.94	56 $\pm$ 6.54	1168 $\pm$ 52.14	4192 $\pm$ 432.40	14,168	6.93	64.5 $\pm$ 5.02
Tanhril										
2006	18	10.5	26	08 $\pm$ 0.24	61 $\pm$ 4.62	948 $\pm$ 34.2	3204 $\pm$ 242.0	12,688	3.85	56 $\pm$ 4.42
2007	Same trees sampled	12		10 $\pm$ 0.48	50 $\pm$ 4.60	1148 $\pm$ 52.42	3694 $\pm$ 562	6000	2.54	52 $\pm$ 3.84
2008	Same trees sampled	28		08 $\pm$ 0.60	62 $\pm$ 5.92	1110 $\pm$ 50.12	3940 $\pm$ 402	13,888	6.07	70.4 $\pm$ 6.23
2009	Same trees sampled	08		06 $\pm$ 0.32	46 $\pm$ 2.23	1202 $\pm$ 48.16	4409 $\pm$ 310	2208	1.07	50.4 $\pm$ 6.45
2010	19	13	26	10 $\pm$ 0.68	52 $\pm$ 6.92	1186 $\pm$ 46.32	3446 $\pm$ 346.32	13,520	5.53	60.2 $\pm$ 5.86

Table 2 ANOVA of the effect of year and population on number of flowers, anthers and pollen grains per tree and fruit set

Response variable and source	Df	MS	F	p
Number of flowers per tree ($R^2 = 0.846$)				
Year	4	52.68	30.42	
Population	1	48.24	28.74	0.0001
Year $\times$ Population	4	40.34	22.64	0.0002
Number of pollen grains per anther ($R^2 = 0.548$)				
Year	4	44.24	27.44	0.5672
Population	1	40.52	20.42	0.0456
Year $\times$ Population	4	32.46	14.62	0.4236
Number of pollen grains per flower ($R^2 = 0.596$)				
Year	4	40.44	26.12	0.4976
Population	1	33.34	16.64	0.0062
Year $\times$ Population	4	26.14	9.26	0.4874
Number of pollen grains per tree ($R^2 = 0.874$)				
Year	4	148.28	64.86	0.0001
Population	1	66.48	34.54	0.0001
Year $\times$ Population	4	30.32	12.93	0.0004
Fruit set ($R^2 = 0.818$)				
Year	4	42.54	20.24	0.0001
Population	1	29.62	18.52	0.0122
Year $\times$ Population	4	20.46	8.32	0.2438

Df degrees of freedom, MS mean square, F F-ratio, p probability

**Fig. 3** Relationship between number of flowers per tree and fruit set percentage per tree

Tectona grandis, *Syzygium cumini*, and *Terminalia arjuna*) (Bhattacharya et al. 1999). The anther dehiscence in *Mesua ferrea* follows the pattern anther dehiscence after anthesis.

Floral architecture in flowering plant is the function of attracting animal pollinators to promote pollen dispersal and pollination success (Fægri and van der Pijl 1971; Fenster et al. 2004). The efficient pollinators, viz. *Apis* and *Xylocopa* bees, observed in *Mesua ferrea* are the function of flower morphometrics to the pollinators' size. *Apis* bee stays on the flower for long time (3–5 min) that generally favours self-pollination. The *Xylocopa* bees visit the flower for a very short time (20–30 s) and make abundant visit to the flowers of whole tree and other trees in a population, which would favour both geitonogamy and xenogamy. Thus, *Mesua ferrea* is supporting random mating in the population.

The effect of time and population on individual pollen production was significant, which is indicating the spatio-temporal pattern of pollen production in *Mesua ferrea*. This pattern is also documented in temperate (Sork et al. 1993; Khanduri and Sharma 2009; Geburek et al. 2012) and tropical trees (Khanduri et al. 2013, 2015). The understanding about the spatio-temporal pollen pattern is deficient in forest trees (Ranta et al. 2008). It is believable that some degree of resources activates flowering and fruiting in trees. As per the model of resource dynamics of Isagi et al. (1997), a tree resolves invariable quantity of reserve food material every year in specified stable environmental conditions. The tree could not reproduce if the energy stage has gone above a definite verge, and the subsequent flowering will diminish the energy reserves of the tree. Principally depending on the ratio for reproductive organs and energy, the resource budget will effect into an even or intermittent reproduction to the years whereby the elevated the aforesaid ratio, the extra messy the time sequence of flowering and fruiting would be. If this pattern exists in nature, the tree species with comparable life history characters, viz. pollen dispersion, mating distance, pollen size, would also contain a parallel temporal pollen pattern. The pattern of temporal pollen production within a population has been accounted for few broadleaved and conifer forest tree species including *Fagus crenata* (Masaki et al. 2008), *Tectona grandis* (Khanduri 2012a), *Schima wallichii* (Khanduri et al. 2013), *Lagerstroemia speciosa* (Khanduri et al. 2015), *Cedrus deodara* (Khanduri and Sharma 2009), *Pinus roxburghii* (Khanduri 2012b) and *P. ponderosa* (Mooney et al. 2011). The resource dynamic model was also followed by various other species viz. *Abies*,

Carpinus, *Fagus*, *Larix*, *Picea* (Geburek et al. 2012) and *Pinus albicaulis* (Rapp et al. 2013).

The percentage of mature fruits/seeds per individual tree was positively correlated with the quantity of flower per tree, which signifies that the number of flowers in *Mesua ferrea* affect the seed production positively, as the high flower density on the tree crown would augment the frequency of pollinators and the pollen grains produced by the flowers will be carried to receptive surfaces of the stigmas of same or other flower to achieve pollination success. Similar positive correlation was obtained between percentage of mature seeds with the quantity of male flowers in various *Carpinus* species from Japan (Shibata et al. 1998). Allison (1990) also reported that the pollination success in *Taxus canadensis* is positively correlated with the frequency of flowering years. It is often important to have an estimate of the total production of pollen per tree for commercially valuable plants, as the production of seeds usually depends on the production of pollen (Faegri and Iversen 1989).

5 Conclusions

Mesua ferrea in this study revealed spatio-temporal pattern of flower, pollen and seed production, which follows the model of resource dynamics (Isagi et al. 1997). This pattern of flower and pollen production accumulates new knowledge on the flower resources of *M. ferrea*, as the flowers of *M. ferrea* are potentially valuable for medicinal purpose to the pharmaceutical companies. Furthermore, the *Apis* and *Xylocopa* bees are the efficient pollinators to achieve the reproductive output in *M. ferrea*.

Acknowledgments This work was supported by the Council of Scientific and Industrial Research (CSIR), Government of India, New Delhi, vide its project no. 38(1186)/08/EMR-II. The authors wish to thank the anonymous reviewers for their valuable suggestions to improve the manuscript.

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