

cline in the emission spectra of PBsomes at lower concentrations might not be attributable to structural damage, as the intensity of PBsome emission could be stimulated by higher doses of glyphosate. Earlier, it has been demonstrated that an increase in the PBsome fluorescence accompanied by blue-shift in the emission peak (644 nm), encompasses conformational change in the PBsome resulting into impairment in the energy transfer from PBsomes to PS II reaction centre<sup>24</sup>.

A corollary of these results suggests that glyphosate-induced impairment in energy transfer in the pigment antenna and build-up of the proton gradient (high energy state) across the membrane account for impairment in the photosynthetic property of *Anabaena* cells.

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## Novel mechanism of distance-oriented bee movement, secondary pollen dispersal and reticulate pollination – a case study in *Melipona panamica*

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The efficiency of secondary pollen dispersal, effect of distance isolation, and possible consequence of reticulate pollination were assessed specifically by movements of stingless bees (*Melipona panamica*) in lowland Neotropical forest vegetation in Panama, because this insect is one of the predominant pollen vectors there. The trial consisted of two identical strips

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(9 m × 45 m) along the forest ground-level discrete vegetation having herbaceous diversity. The design was a 'V', truncated in such a way that the zone, without any vegetation, between the two strips varied from 4.5 to 18 m in width. A nest of *M. panamica* colony was placed at 12 m from the top of the 'V'. Three equal sectors (135 m<sup>2</sup>) were identified in each strip. The bees were marked with different colours according to each sector of one strip, named the donor strip. Almost all bees were marked until their number was nearly balanced between the three sectors. Then, marked and unmarked bees were counted on the donor and recipient strips. Results showed that the foraging area in a given strip is about 405 m<sup>2</sup> and that a mean proportion of 3.45% of marked bees/total number of bees in colony was recovered in the recipient strip. It was found that a barren zone from 4.5 to 18 m in width was not sufficient to completely discourage bees from crossing between two identical resources, but that it significantly reduced cross-pollination. The bees dispersed pollens by bee-bee interactions within the nest, showing high diversity of pollens from outgoing bees, rather than incoming ones. The pollen viability study along the body of exiting bees showed that the pollens remained viable (48–51%) within the bee nest, indicating a possibility of out-crossing by exiting bees at the time of their forage patch and trip change.

STINGLESS bees are abundant in tropical countries. They cannot tolerate cold temperature, and there are many species within two genera, *Melipona* and *Trigona*. These bees are considered as potential pollinators. Modelling processes that control tropical tree population genetics require the knowledge of pollination syndromes and systems. Different perennial bee colonies (honey bees and stingless bees) are functioning continuously as potential visitors to millions of flowers. Bee colonies generally affect pollen dispersal and plant genetic neighbourhood either by pollination service or by robbing, i.e. pollen removal with no pollination or due to aggressive interaction with other visitors. The plant pollinator system always may not concern natural habitat of canopy, and may ignore the dynamics in the forest. Different factors like distance, height, sun and wind exposure, flexibility in travel between sun-drenched and shaded gaps may attain vital importance in pollen dispersal by living animals, and the type of foraging activities, whether it is generalized or specialized, is determined by these factors<sup>1–3</sup>. It is assumed that another new mechanism of pollen dispersal may also be possible as a result of bee-bee interaction and bee-to-bee pollen transfer in colonies, which can produce secondary pollen dispersal. The consequence of secondary pollen dispersal by bees may lead to reticulate pollination. Considerable amount of pollen grains may loosely be adhered to the hairs on the body of the bees when they pick up the grains from flowers and transport them to other flowers or nests. These pollen grains may be exchanged inside the nest (secondary dispersal) due to rub-

bing, aggressiveness or resource depletion by the bees. So, the outgoing bees may show greater pollen diversity on the body surface than incoming ones. If the pollen grains remain viable inside the nests and/or the body surface of outgoing bees, and if the bees change forage patches between foraging trips, then there is a chance of out-crossing among conspecific plants. This mechanism may be considered as reticulate pollination. Here, this novel mechanism of pollen dispersal by stingless bees, *Melipona panamica* was studied experimentally, considering the effect of distance on their movement and viability of pollens on their bodies. Isolation distance seems to be a factor to reduce pollen dispersal both by wind and insect pollinators. Various designs need to be developed to prove this. In a continuous design, with recipient plants evenly placed around a small transgenic source plot, it has been demonstrated that the pollen distribution was leptokurtic and that pollen dispersal may decrease in a particular area<sup>4</sup>. In discontinuous designs, where recipient plants are situated at various isolation distances from the source, the results are less clear. Stringam and Downey<sup>5</sup> found that the contamination might decrease with distance, while Manasse<sup>6</sup> found that this type of design favoured long-distance dispersal. Moreover, a narrow barren zone seems to increase cross-pollination<sup>7</sup>. But, seed contamination may be attributed to insects, which could fly over the non-recipient plants or over areas without any vegetation. On the other hand, studies on the foraging behaviour have often shown that stingless bees individually forage on small areas<sup>8,9</sup> and that they generally visit the nearest flowers in the same row and were strongly directional in their movements<sup>10</sup>. No documentation has been recorded so far on secondary pollen dispersal and reticulate pollination. Besides, in Panama these bees are one of the predominant pollinators<sup>9</sup>. So the purpose of this study was to determine the efficiency of secondary pollen dispersal, effect of distance isolation on bee movement, pollen viability on body surface within the nest and possible consequence of reticulate pollination by *M. panamica*.

The experiment was conducted in two identical strips (9 m × 45 m) along the lowland forest ground-level herbaceous discrete vegetation of a specific multifloral habitat having the plants of *Anacardium excelsum* (Anacardiaceae), *Begonia involucrata* (Begoniaceae), *Caladium bicolor* (Araceae), *Callisia ciliata* (Commelinaceae), *Capparis frondosa* (Capparaceae), *Commelina erecta* (Commelinaceae), *Cordia panamensis* (Boraginaceae), *Cyperus haspan* (Cyperaceae), *Guzmania lingulata* (Bromeliaceae), *Herpetacanthus panamensis* (Acanthaceae), *Hymenocallis pedalis* (Amaryllidaceae), *Hyptis capitata* (Lamiaceae), *Jatropha curcas* (Euphorbiaceae), *Melothria pendula* (Cucurbitaceae), *Oenocarpus panamanus* (Arecaceae), Orchidaceae, Poaceae, *Pseudobombax septenatum* (Bombacaceae), Rubiaceae, Scrophulariaceae and *Vernonia patens* (Asteraceae). *M. panamica* usually

visits plants like *B. involucrata*, *C. frondosa*, *C. erecta*, *H. pedalis*, *H. capitata*, *M. pendula*, *V. patens*, Orchidaceae, Rubiaceae and Scrophulariaceae. The design had the shape of a 'V', truncated at the base in such a way that the zone, without any vegetation, between both strips varied from 4.5 m in width at the base of the 'V' to 18 m in width at the top. Three equal areas ( $135 \text{ m}^2 = 9 \text{ m} \times 15 \text{ m}$ ) were considered in each strip; sector I (corresponding to the part of the design with a barren zone from 4.5 to 9 m); sector II (corresponding to the medium part of the design with a barren zone from 9 to 13.5 m) and sector III (corresponding to the part of the design with the largest barren zone, i.e. from 13.5 to 18 m). The plants selected for this experiment were *H. capitata*, *V. patens* and *H. pedalis* for sectors I, II and III respectively. A bee nest was placed at 12 m from the top of the 'V'. Therefore, sector III was the closest to the bee nest. With the aim to compare the attractiveness of the two strips along the flowering period and the distribution of the bees in the sectors, the number of available flowers/ $\text{m}^2$  and the number of bees were evaluated at 12 randomly selected dates and at several times in the afternoon on both strips. The bees were counted regularly for 15 min by walking along the strips. To observe the movement of the bees within and between the strips, foraging *Melipona* bees were marked with three different colours for each of the three sectors in one of the two strips, considered as the donor strip. The other was the recipient strip. The marking was made at the beginning of the afternoon when the foraging activity was high. Almost all the bees foraging in the strip were marked. In addition, they were marked until their number was balanced between the three sectors of the donor strip. The experiment was repeated for five days, successively using three colonies. The total number of marked *Melipona* bees could vary from 38 to 60 according to the date of the experiment. The movement of bees within the donor strip was estimated by the percentage distribution, in each sector, of the proportion of the recovered bees marked with one of the three colours. These observations were made 1.5 and 3 h after the marking time. The observation of the movements between both strips was performed soon after marking. The marked and unmarked bees were counted in the recipient strip to evaluate the recovery rate of the population. Controls were also made in the donor strip to determine the remaining marked bees after the marking phase. Counts of marked or unmarked bees were analysed in two ways: (i) recovery rate (number of marked bees recovered after the time  $t_x$ /number of bees initially marked at  $t_0$ ) and (ii) proportion of marked bees/unmarked bees. The marking phase lasted for about 22 min and the counting length was about 15 min. The first recovery rate in the recipient strip was determined quickly after marking, i.e. after 22 min, then after 1.5 h ( $\pm 15$  min), whereas the recovery rate in the donor strip was controlled 1.5 h ( $\pm 15$  min) after marking. Statistical analysis was performed by a

one-way analysis of variance (ANOVA) followed by a Newman-Keuls test at probability 5%. For pollen viability studies on the body surface of the bees within the nest, pollen grains were isolated from their bodies when bees were coming out from the nest early next morning. A one-inch long beehive straw tube was kept at the entrance of the nest before the bees left early in the morning. When bees (ca. 250–350) were exiting the nest, the pollen grains from their body get detached and adhere to the straw tube. The whole portion of this tube was then washed with Alexander's stain<sup>11</sup> on a microscopic slide, mounted and viable pollen grains were scored under light microscope at 400X magnification. This stain is a dye containing malachite green and acid fuchsin, which differentially stains aborted and viable pollen; malachite green stains cellulose in pollen grains, and acid fuchsin stains the protoplasm. Thus aborted pollens appear green, while pollens with protoplasm, i.e. viable appear pink. The experiment was repeated for ten days using three bee colonies at three different sites.

The flowering of different herbs along the forest ground-line vegetation was the same in both strips. The density of available flowers/ $\text{m}^2$  ranges from 25 to 90 flowers/ $\text{m}^2$  and was less than 60 flowers/ $\text{m}^2$  at the end of the observation period. At a given time, the total number of foraging bees was equal on the two strips (mean donor = 105 vs mean recipient = 108). Their abundance was not different between sectors (Table 1).

A comparison of the percentage of marked bees showed that most of them occupied in their source sector. Marking the bees with colour I revealed the significantly different percentage distribution between sectors I and II and sector III. It was significantly different between sector II and sectors I and III while marking with colour II. But marking with colour III showed significant difference between sector III and sectors I and II (Table 2).

Movement of bees between the donor and recipient strips was found following the recovery rate of bees in two strips. Significant difference ( $P = 0.0013$ ) of recovery rate between donor and recipient strips was obtained.

**Table 1.** Mean total number of foraging *Melipona* bees in each sector ( $\pm$  SE)

	Sector I	Sector II	Sector III	Significance
Donor	12.75 $\pm$ 2.1	11.35 $\pm$ 1.7	11.2 $\pm$ 1.6	NS; $P = 0.80$
Recipient	12.25 $\pm$ 1.65	12.85 $\pm$ 1.55	11.85 $\pm$ 1.7	NS; $P = 0.90$

**Table 2.** Distribution (%  $\pm$  SE) of marked bees in each sector

	Sector I	Sector II	Sector III	Significance
Colour I	<b>27.05 <math>\pm</math> 5.1 (a)</b>	18.5 $\pm$ 5.6 (a)	4.15 $\pm$ 2.6 (b)	S; $P = 0.0103$
Colour II	14.1 $\pm$ 4.2 (b)	<b>28.4 <math>\pm</math> 5.2 (a)</b>	7.4 $\pm$ 1.4 (b)	S; $P = 0.0078$
Colour III	2.3 $\pm$ 2.2 (b)	9.7 $\pm$ 8.2 (b)	<b>37.5 <math>\pm</math> 7.9 (a)</b>	S; $P = 0.0061$

Results followed by the same letter are not significantly different.

In donor strip the recovery rate was 5 times (27.3%) higher than in the recipient strip (5.55%). A similar significant difference of recovery rate (donor = 27.3%; recipient = 7.35%) was obtained keeping the same time limit ( $90 \pm 15$  min after marking) between both observations. The calculation of the proportion of marked bees/total number of marked and unmarked bees in both strips (after the same time limit) showed the effect of renewal of foraging population; and it has been seen that unmarked new bees diluted the marked bees after a while. The marking of bees was performed in the donor strip to observe their movements from donor to recipient. Percentage distribution of marked bees was significantly higher in donor strip than recipient strip. So, the proportion of bees in the recipient strip seems to be lower. It also showed (Table 3) that bees which have come from the donor strip represented a small part of the total foraging individuals (2.55%). But 1.5 h later this proportion could reach 13.2% in a sector of recipient strip. On an average the proportion was 3.45% (45 observations in three sectors with 15 replicates).

Pollen grains were isolated from the body surface of exiting bees early next morning to observe diversity and viability. It has been seen that the incoming bees carried less diversity of pollen (4–5 pollen morph species, e.g. Asteraceae, Amaryllidaceae, Begoniaceae, Lamiaceae) the day before, whereas the exiting bees early next morning carried greater diversity (9–10 pollen morph species, e.g. Asteraceae, Amaryllidaceae, Begoniaceae, Boraginaceae, Capparaceae, Commelinaceae, Cucurbitaceae, Lamiaceae, Rubiaceae, Scrophulariaceae) of pollen. Similar observations were noticed in repeated experiments for 10 successive days using three bee colonies, considering all the bees of a colony. Bees can carry pollen grains on their bodies from plants which they have not visited (cross pollen), because they rub against each other in the hive and acquire pollen grains from nest-mates. Thus bees carry on their bodies, a higher diversity of pollen grains than could be expected from their individual visits to flowers. Thus bee-to-bee pollen transfer (secondary pollen dispersal) exists. Viability studies revealed that a more or less similar extent of viable pollen grains (48–51%) occur in the

body surface of the bees (Table 4). These viable grains on the body of the bees may join again in reproductive gene flow, when such bees visit virgin and receptive conspecific flowers of different habitats. This is called reticulate pollination. This phenomenon occurs when bees change forage patches between foraging trips.

It is stated that both strips were equally attractive and that no gradient in density of bees was noticed along the strip according to the distance from the bee nest. The bees tend to stay in a confined area; some of them flew from one strip to the other. So, the movement of *M. panamica* in this particular habitat becomes distance-oriented. They have been reporting on movement and pollen-collecting behaviour of various bees at different habitats<sup>12–15</sup>. The recovery rate in the recipient strip was low, but pollen dispersal by *M. panamica* from one plant genotype to another becomes pertinent, because the most important risk occurs when both genotypes are visited consecutively<sup>10</sup>. The analysis of recovery rates also showed that it is difficult to mark and observe bees in appropriate timescales, because the foraging population is always moving and renewing. This preliminary study had led us to conceive a more adequate protocol to solve the problem and find a probabilistic model to analyse the pollen/gene dispersal by flow of bees between the six sectors.

If there are particular rules that determine genetic out-crossing, one of them must be pollen viability. The viability of pollens must continue over a period long enough to allow pollen dispersal between trees. A bee must be recruited or make a foraging decision to use more than one foraging area; so pollen grains left on surfaces of the nest or dispersed directly from one bee to another (secondary dispersal) may also join with the pool of pollen/gene flow for out-crossing (reticulate pollination). Bee-to-bee pollen transfer inside the nest becomes possible, showing greater pollen diversity on the bodies of outgoing bees than incoming ones. Various factors like rubbing, aggressiveness, resource depletion, electrostatics properties are associated with bee-to-bee pollen transfer (secondary pollen dispersal), the consequence of which is reticulate pollination<sup>16–18</sup>. Secondary pollen dispersal and reticulate pollination have far-reaching consequences with regard to gene flow and increase in floral diversity in various isolated, disturbed, changed and even destructed habitats.

**Table 3.** Proportion of marked bees/total number of marked + unmarked foraging bees in each strip

Donor	90 ± 15 min after marking	47.1%
Recipient	90 ± 15 min after marking	13.2%

**Table 4.** Viable pollen (% ± SE) on body surface of bees in each site

	Colony I	Colony II	Colony III
Site I	49.4 ± 5.68	51.2 ± 8.07	47.6 ± 3.65
Site II	48.8 ± 10.03	49.2 ± 4.92	50 ± 6.48
Site III	50.6 ± 5.50	50.4 ± 3.04	49.2 ± 5.40

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## Subsurface geometry of Hyderabad granite pluton from gravity and magnetic anomalies and its role in the seismicity around Hyderabad

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The subsurface geometry of Late Archaean–Early Proterozoic Hyderabad granite pluton is delineated from gravity and magnetic data, and its possible role in the recurring local earthquakes evaluated. The

Bouguer anomaly map of the region shows that the pear-shaped Hyderabad granites are emplaced as discrete plutons, though these may form part of a composite batholith. Extension of the Hyderabad batholith towards the west under Deccan traps is delineated. Analysis of the gravity and magnetic anomalies shows that the pluton has a total horizontal dimension of  $100 \times 100 \text{ km}^2$  and a vertical extension of about 4–5 km. However, the discrete roots of this granite body extend to over 10 km depth. The delineated granitic body, because of its elastic property contrast with the surrounding rock, may act as the stress concentrator of far-field compression due to the motion of the Indian plate, and together with the pre-existing faults and weak zones in the form of morphotectonic knots in the Jubilee hill, are suggested as twin cause mechanisms for inducing the present-day local earthquakes of the Hyderabad region, even at a lower differential stress.

K-GRANITE plutons, when exposed at the surface of the continental crust in shield areas, provide ample information to geoscientists to understand the origin and evolutionary history of the ancient continental crust. Such K-granite plutons named after their places of occurrence, viz. Chittoor, Closepet, Karimnagar, Lepakshi, Mahbubnagar, Ramgiri, Warangal, etc. are widespread in the Eastern Dharwar Craton (Figure 1). These are generally isolated and are emplaced along major lineaments as narrow bands and veins. In the northeastern Dharwar Craton, they attain batholithic dimensions in which the older granitoids occur as xenoliths and enclaves. The Hyderabad granite pluton emplaced into the ‘Peninsular gneisses’ is least studied, geologically and geophysically, although it is the largest in occurrence and has a variable composition. Its extension and possible association with the Karimnagar, Warangal and Mahbubnagar granites is a subject of speculation and debate<sup>1</sup>.

Besides, inclusions of these granite plutons may act as a stress concentrator of far-field compression: a mechanism proposed for minor, low-energy release earthquake activity in hitherto considered stable continental regions<sup>2</sup>. Hyderabad granite pluton is no exception. A moderate seismicity is being repeatedly experienced in the recent past that can be related to the Hyderabad granite pluton<sup>3</sup>. The first reported earthquake of magnitude 3.5 occurred on 14 January 1982, adjacent to the Osmansagar reservoir, west of Hyderabad<sup>4</sup>. This was followed by the Medchal earthquake of magnitude 4.5 on 30 June 1983. A tremor of magnitude 1.6 on 25 August 1984 was felt in Kushaiguda and three tremors, the largest of magnitude 2.2 on 29 November 1984, were felt in Saroor Nagar. The Jubilee hills experienced micro-tremor activities of magnitudes 2.0, 1.2, 1.7 and 2.7 in the 1994, 1995, 1998 and 2000 respectively<sup>3–5</sup>. After the deadly earthquakes of Latur, Jabalpur and Bhuj, recurrence of local earthquakes in the city limits of Hyderabad and Secunderabad is a matter of grave concern. Being a fundamental tectonic feature

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