

Pentamerous fossil flowers and fruits from Rajasthan reveals the dominance of flowering plants in the early Palaeogene of India

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The dominance of angiosperms, achieved around the late Cretaceous–early Palaeogene time, can be observed through multiple well-preserved fossil flowers and fruits described from the early Palaeogene sediments of Bikaner and Barmer (Rajasthan, India). Here, we report twelve pentamerous fossil flowers categorized into three morphotypes mainly based on their petal's shape and pattern. Fossil pollen *Rhoipites anacardioides* Ramanujam, extracted from the preserved androecium of one of the fossil flowers, has shown strong affinity with the modern pollen of Anacardiaceae. The pentamerous fossil fruit encompassing a single whorl of five carpels alternating with petals is similar to the extinct genus *Chaneya* Wang and Manchester. These fossils provide a cinematic picture of the beautiful flowering and fruiting phases during the early Palaeogene, well known for the major diversification of angiosperms.

Keywords: Angiosperm, Anacardiaceae, *Chaneya*, Palana Formation, Rutaceae.

TAKING advantage of their ability to encompass vibrant flowers, angiosperms have become a significant part of the terrestrial ecosystem since the Early Cretaceous, and proof of their rapid diversification and spectacular rise to dominate other plant groups has been documented in the form of fossils in the concurrent rocks. Profuse fossil evidences from the early Palaeogene horizons indicate the period for their major diversification, when angiosperms were present everywhere conquering all the land areas and reaching their cryptic diversity. Although a recent study of a well-preserved flower bud from Inner Mongolia of China¹ shows early existence of angiosperms in the Jurassic, yet the dominance of flowering plants is believed to impact long-established plant groups like gymnosperms. However, the transition from gymnosperm dominated to angiosperm-rich palaeovegetation is evident from the Cretaceous in palaeotropics.

A number of fossil flowers preserved as charcoal and in amber^{2,3} have been reported from the Indian subcontinent, along with copious records of fossil fruits^{4–9} constituting a significant element of palaeobotany today. The present study epitomises the presence of fruit and flower impressions

from the early Palaeogene successions of western Rajasthan, India, which eventually signify the rich angiosperm diversity thriving at the time ~60 Ma.

During palaeontological fieldwork, well-preserved fossil flowers and fruits were collected from the Gurha lignite mine (27°52'26"N; 72°52'20"E), Bikaner and Kapurdi clay mine (25°54'30"N; 70°22'33"E) Barmer, belonging to the Palana Formation of late Palaeocene–early Eocene age¹⁰ and early Eocene age⁹ respectively. Macroscopic images of fossils were obtained using Canon SX 100 IS camera under the natural light and stereo zoom Leica MZ 16 microscope for microscopic images. Morphological terminology used to describe our fossils is after Wang and Manchester¹¹.

To recover pollen grains, the scraped sediment from the preserved stamen portion of the fossil flower (Figure 1 c) was macerated using the standard procedure¹² and photographed using Nikon Eclipse I 90 microscope. The fossil type specimens, along with palynomorphs slides, are housed in the museum of the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow.

The systematic study included twelve fossil flowers, three fossil fruits and a morphotype of pollen. According to their shapes and attachment types, we have categorized fossil flowers into three categories, i.e. morphotype I, morphotype II and morphotype III. The systematic description of the fossils is given below.

Morphotype I, two fossil flowers (Figure 1 a and e): Fully bloomed; zygomorphic; hypogynous; pedicel and calyx not preserved; receptacle not visible; corolla well preserved; polypetalous with five petal lobes; 1.1–1.6 cm in length, 0.6–1.2 cm wide; obovate to oblong; petals with entire margin, nearly equal to sub-equal in size; base present, wide cuneate; apex present, obtuse, rounded to convex in shape, petal arrangement valvate, sinus between petals angular, acute, deeply incised; petal venation distinct, longitudinal primary vein and sub-parallel veins present, all veins arising independently from the base; primary vein slightly stronger than sub-parallel veins, mainly craspedodromous, dichotomous branching present, extending to the apex or branching in course to apex at an acute angle; central disc, 0.4–0.6 cm in diameter; androecium and gynoecium not preserved.

Morphotype II, three fossil flowers (Figure 1 b–d): Well preserved and almost complete; fully bloomed, zygomorphic; hypogynous; pedicel well preserved in some specimens, 0.2 cm preserved length, 0.3 cm wide; receptacle preserved; corolla well preserved; five petals present, polypetalous; 1.2–1.4 cm in length, 0.3–0.6 cm wide; elliptic, petals with entire margin, nearly equal in size; base present, predominantly convex to wide cuneate; apex present, acute to acuminate without dripping tip, petal arrangement valvate, sinus between petals angular, acute, deeply incised; petal venation very faint; stamen poorly preserved, carpel indistinctly visible.

Morphotype III, seven fossil flowers (Figure 1 f–k and n): Flowers fully bloomed to bud; zygomorphic; hypogynous;

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Figure 1. Recovered fossil flowers and pollen. *a*, Flower from the Barmer basin. *b–k, n*, Flowers from the Gurha lignite mine. *f*, A bud pointed by black arrow. *j*, Enlarged view of petal venation. *l, m*, The fossil pollen *Rhoipites anacardioides* Ramanujam recovered from the central portion of specimen *c* having preserved stamens. Scale represents 1 cm for *a, d, e, f, j, k, n*; 0.5 cm for *b, c, g, h, i*; 10 μ m for *l, m*. Specimen numbers: BSIP 1/42199, 2/42199 (*a, e*). Specimen numbers: BSIP 1/42200, 2/42200, 3/42200 (*b–d*). Specimen numbers: BSIP 1/42201, 2/42201, 3/42201, 4/42201, 5/42201, 6/42201 (*f–k, n*). Specimen numbers: BSIP 1/17174, 2/17174 (*l, m*).

pedicel well preserved in some specimens; receptacle is swollen; calyx not preserved; corolla well preserved, usually twisted; pentamerous, polypetalous; 0.8–1.2 cm long, 0.4–

0.6 cm wide; elliptic to obovate, petals with entire margin, nearly equal to sub-equal; base present, wide cuneate; apex present, acute to obtuse, rounded, convex to irregular margin;

petal arrangement valvate; sinus between petals angular, acute, deeply incised; petal venation distinct, longitudinal primary vein and sub-parallel veins present, all veins arising independently from the base; primary vein slightly stronger than the sub-parallel veins, mainly craspedodromous, dichotomous branching present, extending either to the apex or branching in course to apex at an acute angle; stamen poorly preserved, carpel not visible.

Pollen grains recovered from Morphotype II were identified as *Rhoipites anacardioides* Ramanujam¹³ and described below.

Genus: *Rhoipites* Wodehouse¹⁴

Species *Rhoipites anacardioides* Ramanujam¹³ (Figure 1 l–m)

Pollen grains were isopolar monads, prolate to sub-prolate in equatorial view, size 25–35 × 20–26 μm, tricolporate, longicolpate, thick and long colpi reaching up to poles, tapered or sharp ends, tiny apocolpium region, distinct lalongate ora, sexine thicker than nexine, tectate, surface essentially supra striato-infra microreticulate, slightly sinuous, fine and narrow muri branched at places, more or less meridionally aligned, becoming more parallel near the apocolpium.

Pollen grains described here matched the description of *Rhoipites anacardioides* given by Ramanujam¹³ which are characterized by striate-reticulate exine ornamentation. However, in the present specimens, supra striato-infra microreticulate exine sculpture was distinctive. Wodehouse¹⁴ proposed the botanical affinities of *Rhoiptes* to the modern genus *Rhus typhina* (Anacardiaceae). However, later on, affinities of different species were given to various modern genera^{13,14}. The longicolpate pollen with supra striato-infra microreticulate exine sculptures in present specimens closely resembled the pollen of *Rhoea* tribe¹⁵ of Anacardiaceae.

The lack of well-preserved reproductive features in our fossil flowers constrains tracking down their exact affinity, but the presence of pentamerous polypetalous petals and valvate aestivation suggest their apparent affinity to various angiosperm families, i.e. Anacardiaceae R.Br., Araliaceae Juss., Boraginaceae Juss., Geraniaceae Juss., Oxalidaceae R.Br., Polygonaceae Juss., Ranunculaceae Juss., Rosaceae Juss., Saxifragaceae Juss. and Violaceae Batsch. However, based on the pollen extracted from the central portion of one of the flowers (Figure 1 c; Morphotype II), we can affirm its close resemblance to Anacardiaceae.

Family: Rutaceae Juss. Vel Simaroubaceae DC.

Genus: *Chaneya* Wang and Manchester¹¹

Species: *Chaneya oeningensis* Teodoridis and Kvaček

Fruit c.f. *Chaneya* Wang and Manchester (Figure 2)

Three fossil fruits, five-lobed, calyx surrounding an orbicular to pentagonal central region; central disc 2.57–2.78 mm in diameter; five sepals with entire margin, almost equal in size, 9.33–10.4 mm long, 2.92–3.27 mm broad, mostly elliptic to ovate, free; base present, wide cuneate to convex base; apex present, acuminate without dripping tip, angle acute; sepal arrangement valvate; sinus angular, acute, deeply incised; venation distinct, usually consisting of three to five longitudinal primary and sub-parallel veins, all veins arising independently from the base; primary vein slightly stronger than lateral veins and extending up to the apex, mainly craspedodromous; sub-parallel slightly weaker, dichotomous branching in course to apex, branching at an acute angle, secondary veins very faint, some showing bifurcation (dichotomous branching) at an acute angle; gynoecium apocarpous, single whorl of five carpels alternating with sepals.

The peculiar morphological features of our fossil fruit, such as pentamerous calyx with elliptic to ovate shape and the presence of a distinct single whorl of five carpels alternating with sepals, show its close proximity to the extinct genus *Chaneya* Wang and Manchester¹¹. Two of its species have been reported from the Eocene sediments of North America (*Chaneya tenuis*) and the Miocene of southeast China (*C. kankangensis*). In addition, three more fossil species have been described, i.e. *C. oeningensis* from the Miocene of Germany¹⁶, *C. membranosa* from the late Miocene of Poland¹⁶ and *C. hainanensis* from the Eocene of South China¹⁶. Our fossil was compared with the known *Chaneya* fossils and

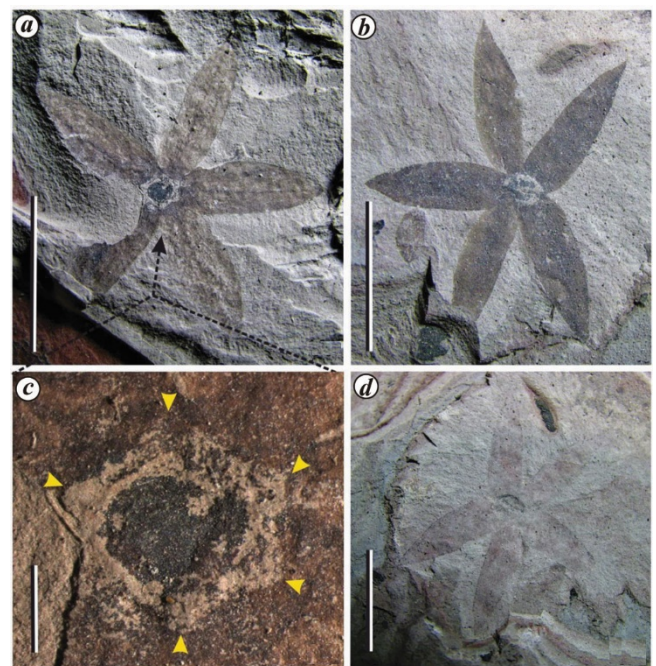


Figure 2. Fossil fruit impressions having five lobes. *a, b, d*, Fossil fruits retrieved from the Gurha lignite mine, specimen numbers: BSIP 1/42202, 2/42202, 3/42202. *c*, Enlarged view of the central portion of the fruit showing five carpels in one whorl alternating with sepals marked by yellow arrows. Scale represents 1 cm.

found dissimilarity with *C. tenuis*, *C. kokangensis*, *C. membranosa* and *C. hainanensis* in having two whorls of carpels compared to single whorls in our fossil. As *C. oeningensis* was found similar to our fossil in the presence of a single whorl of five carpels alternating with sepal and size range of sepal length and width, we have described the present fossil under the same specific epithet.

Flowers are the ideal source of phylogenetic information and hold a key position in reproductive biology, perhaps facilitating angiosperm diversification through their influence on speciation and extinction rates¹⁷. The present fossil evidences provide a glimpse of the abundance of flowering plants in tropical regions of the Indian subcontinent during the early Palaeogene time when a major diversification of angiosperms took place.

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Biomass, carbon stock and sequestration of predominant tree species of Vikarabad Natural Forest lands, Telangana, India

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A study was conducted during 2019–20 to document the predominant tree species, biomass, carbon stock and sequestration of undisturbed natural forest lands (40 years) across the 18 mandals of the Vikarabad district (3386 sq. km area with 109,325 population) of Telangana state. Results revealed that the predominant tree species consisted of *Eucalyptus grandis*, *Tectona grandis*, *Azadirachta indica* and *Ficus benghalensis*. The highest total biomass, carbon stock and sequestration were registered with *Eucalyptus grandis* (179.08, 89.54 and 328.62 tonne ha⁻¹ respectively) followed by *Ficus benghalensis* (140.66, 70.33 and 258.10 tonne ha⁻¹ respectively) and *Tamarindus indica* (51.60, 25.80 and 94.68 tonne ha⁻¹ respectively) and minimum with *Pongamia pinnata* (0.31, 0.15 and 0.57 tonne ha⁻¹ respectively). Deviation in volume, carbon stock and sequestration was due to the variation in height, girth and biomass of individual tree species. The results identified the potent tree species with high C stocks and sequestration for regions with similar climates and useful for environmental education to the people for climate change mitigation.

Keywords: Biomass, carbon stock, forest lands, predominant tree species, sequestration, undisturbed forest lands.

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