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Rugaspermum minuta – a new species of the seed genus *Rugaspermum* from the Triassic of Nidpur, India

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Abstract: This paper provides a description of a new species of *Rugaspermum* D.D.Pant & Basu, *R. minuta* Bhowmik & Parveen, from the Nidpur Triassic beds. The dispersed seeds were recovered after macerating large chunks of shale in hydrofluoric acid. The structurally preserved compressed seed is platyspermic, orthotropus, and oval- to barrel-shaped with a short beak-like micropyle. The surfaces of the seeds are wrinkled and there is a wide lateral ridge running from the apex to the base on both the obverse and reverse sides. Upon maceration, the seed yielded 4 membranes: outer, inner, nucellar, and megaspore membranes. The outer cuticle of the integument is thick and nonstomatiferous, while the inner cuticle is thin and delicate. The nucellar membrane is granular. The megaspore membrane is tough and dark-stained, showing obscure polygonal cell outlines. The pollen chamber is disc-shaped, containing the *Rugapites* D.D.Pant & Basu type of pollen grains.

Key words: Triassic, *Rugaspermum, Rugapites,* megaspore membrane, pollen

Introduction

Several dispersed, compressed seed genera, such as *Savitrispermum* Manik (1987), *Nidispermum* Manik (1987), *Pyriformispermum* Manik (1987), *Rotundaspermum* Manik (1987), *Pantiaspermum* Manik (1987), *Rostrumaspermum* S.C.Srivast. & Manik (1990), *Delevoryaspermum* S.C.Srivast. & Manik (1993), *Tayloriaspermum* S.C.Srivast. & Manik (1993), *Sahnispermum* S.C.Srivast. & Manik (1993), *Cupolaspermum* S.C.Srivast. & Manik (1993), *Konaspermum* S.C.Srivast. & Manik (1993), *Urceolaspermum* S.C.Srivast. & Manik (1993), and *Chaturvedeacarpon* S.C.Srivast. et al. (2001), with interesting external and anatomical features were reported earlier from the Triassic shales of Nidpur. In addition to the above, 3 species of the seed genus *Rugaspermum* D.D.Pant & Basu (1977) were also described from Nidpur.

The present article provides a description of a new species of *Rugaspermum* D.D.Pant & Basu (1977), *R. minuta* Bhowmik & Parveen. Compressed seeds of the new species are found frequently occurring intermixed with other fragmentary plant remains in the carbonaceous residues left after hydrofluoric acid (HF) maceration of Triassic shales from Nidpur.

At a cursory glance, the new seeds seemed to resemble *Rugaspermum insigne* D.D.Pant & Basu (1977), but closer examination revealed the seeds to be quite different from *R. insigne* and also different

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from the 2 other known species of *Rugaspermum*, *R. media* D.D.Pant & Basu (1977) and *R. obscura* D.D.Pant & Basu (1977).

Seeds of *R. minuta* are conspicuously smaller and oval to barrel-shaped; they have a wide lateral ridge and the micropylar end shows a rectangular ridge. Moreover, cells of the outer cuticle of the integument are apparently nonpapillate. Despite these differences, the new seeds resemble earlier described species of *Rugaspermum* in having a similar wrinkled surface and being pollinated by the *Rugapites* D.D.Pant & Basu type of (1977) pollen grains.

Since pollen grains resembling *Rugapites* were earlier described from a miofloral assemblage of Nidpur Triassic as a genotype of sporae dispersae *Weylandites* by Bharadwaj and Srivastava (1969), Balme (1995) suggested that the micropylar canal and pollen chamber of *Rugaspermum* seeds contained *Weylandites* pollen grains instead of *Rugapites*. In our opinion, however, the possibility of the pollinating pollen grains being *Rugapites* is more certain than *Weylandites* because the synangiate pollen organ of *Rugatheca* D.D.Pant & Basu (1977) occurred in close association with *Rugaspermum* seeds.

Geology

The Nidpur beds occur in the Gopad River section of the western part of Singrauli Coalfield, Sidhi District, Madhya Pradesh, India. The sediments that are exposed downstream on the bank of the Gopad River about 2 km NE of the village of Nidpur (24°7′N, 81°53′E) are located between 2 faults, F^2 and F^3 (Figure 1, after Raja Rao, 1983). The area

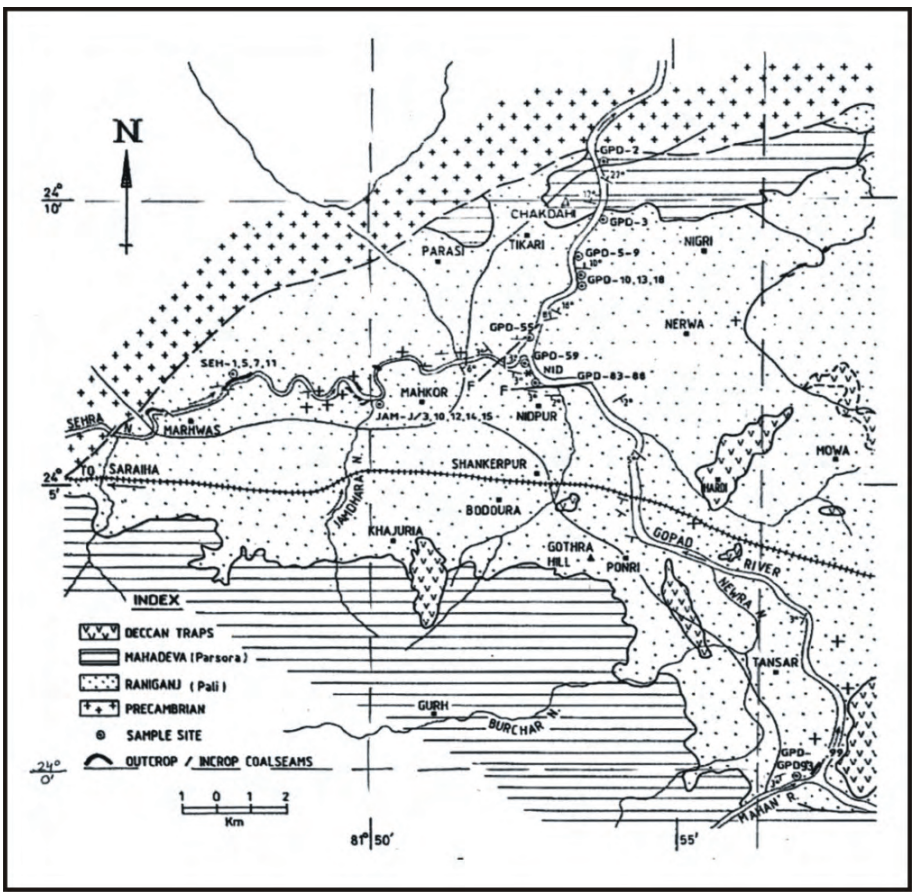

Figure 1. Map of the study area: geological map of the north-west section of Singrauli Coalfield, showing Marhwas area, where the Nidpur beds (asterisk) are situated. The yielding samples, marked by dots within a circle, are indicated along the traverses taken. NID (asterisk) indicates the position of Sample Nos. NID-4,5,8,10 (after Raja Rao, 1983).

south of the confluence of Sehra Nala with the Gopad River has been considered to be the "Nidpur beds," and the area is known as the "Marhwas area" (Tiwari & Ram-Awatar, 1989). The Marhwas area is located in the Singrauli basin and the Nidpur beds occupy the western portion of the basin, occurring at the junction of the Damodar, Satpura, and Son-Mahanadi grabens.

The countryside around Marhwas and Nidpur is a flat alluvial plain with exposed Triassic sediments in the river cuttings. The Nidpur bed along the Gopad River cuttings contains carbonaceous compressions preserved on grey, medium-grained (Majumdar, 1981), micaceous shale. The sediments above and below the Nidpur beds have yet to be exposed. The plant remains of the bed appear to be allochthonous and are not buried in situ.

Materials and methods

Dispersed seeds preserved as compressions were collected from the Triassic shales along the banks of the Gopad River near the village of Nidpur, Marhwas area, Sidhi District, Madhya Pradesh, India. The seeds of *Rugaspermum minuta* are found scattered on the shales together with other mega- and microfossil plant remains. Structurally preserved seeds were extracted out of the shale by dissolving the rock in 40% HF. The seeds were sorted out under a stereo-binocular microscope (Olympus SZ61) after washing the extracted organic residues from the rock repeatedly in water. Surface features of the dry seeds were studied after mounting them on a cavity slide and observing them under unilateral incident light. Some seeds were subjected to maceration in Schulze's fluid to study the cuticular details of the internal structures. The cuticles were mounted in safranin-stained glycerine jelly and examined under a trinocular microscope (Olympus CH20i). Photographs of the seeds were taken with a Wild Leitz microscope, Leica DM 2500 microscope, and SONY DSC-W70 digital camera. All slides and seed specimens were deposited in the Divya Darshan Pant Collection Museum of the Botany Department of Allahabad University, India.

Systematics

Gymnospermopsida

Gnetales?

Incertae sedis

Genus – *Rugaspermum* D.D.Pant & Basu, 1977

Type species: *Rugaspermum insigne*

Rugaspermum minuta Bhowmik & Parveen sp. nova.

Diagnosis: Seeds small, platyspermic, orthotropous, about 1.0-2 mm long × 1.0-1.5 mm wide, oval to barrel-shaped. Micropylar end of seed showing a rectangular ridge enclosing a shallow depression, within which lies a partially immersed to slightly projecting short, beak-like micropyle. Chalazal end rounded in outline, but becoming narrow at base to form a rectangular chalazal hole about 700 μm wide. Seeds showing a wide lateral ridge running from apex to base on both obverse and reverse sides when compressed along principle plane. Surface of seeds wrinkled, showing transverse to oblique wrinkles and fine, irregularly running, longitudinal striations. Seeds upon maceration yielded 4 membranes: outer, inner, nucellar, and megaspore membranes. Outer cuticle of integument thick, nonstomatiferous, about 15 μm in thickness, showing rectangularly elongated, nonpapillate cells arranged in longitudinal rows. Cells measuring about 25-63 μm long × 10-15 μm wide with straight, almost uniformly thickened lateral and cross walls about 13 μm in thickness. Closely adhering to thick outer cuticle is the inner cuticle of the integument, which is thin, delicate, composed of polygonoid thin-walled cells appearing to be arranged in vertical rows. Cells measuring 35-70 μm long × 30-58 μm wide, with straight cell walls about 5 μm thick and containing a wide cell lumen. Inside the inner cuticle of the integument is the nucellar cuticle, which appears granular, consisting of rectangularly elongated, thin-walled cells, measuring about 25-38 μm long × 5-10 μm wide with straight to slightly sinuous cell walls, averaging 4 μm in thickness. The innermost integument of the seed is the megaspore membrane, which is tough, dark coloured, showing obscure polygonal cell outlines measuring about 40-75 μm long × 25-50 μm wide. It occupies a large part of the seed area and is visible at a small distance below the

micropylar canal. All 3 membranes, inner to outer cuticle, are free at the micropylar end but become fused with each other lower down. Micropylar canal small, about 160 μm long × 40 μm wide, generally appearing immersed, rarely protruding in the form of a small beak. Apical end of micropyle often dilated in the form of a funnel in macerated seeds. Pollen chamber forming a shallow, disc-shaped depression or pit. Both pollen chamber and micropylar canal containing unwinged, ellipsoidal to spheroidal *Rugapites*-type (Pant & Basu, 1977) pollen grains that occur frequently clustered and rarely isolated. Size of individual spheroidal pollen grains averaging 55 μm × 53 μm, while the ellipsoidal forms range from 38 to 68 μm long × 25-53 μm wide.

Derivation of name: The specific name *minuta* refers to the small size. Holotype – Slide No. 53,311.

Repository – Divya Darshan Pant Collection, Botany Department, University of Allahabad, Allahabad, India.

Horizon – Triassic (Middle Gondwana).

Locality – Nidpur village, Marhwas area, Sidhi District, Madhya Pradesh, India.

Description: More than 50 seeds of *Rugaspermum minuta* extracted from the rock matrix were examined. The length of all seeds was found to be almost the same, but their widths showed variation. In broadly oval forms, the seeds appeared to be as wide as long. The platyspermic seeds of *R. minuta* show a wide to narrow lateral ridge on either surface when compressed along the principle plane (Figure 2). Incident light examination of the surface of well preserved dry seeds showed fine longitudinal striations corresponding to the rows of vertically arranged rectangularly elongated cells of the outer epidermis of the integument (Figure 2). Besides vertical striations, the surface of most seeds also showed obscure to distinct, widely to closely spaced, transverse to obliquely running wrinkles (Figure 2). The wrinkled appearance of the seeds seems to be due to the unevenly thickened cross walls of transverse rows of epidermal cells of the outer integument. Maceration of those seeds in which fine vertical striations or transverse to oblique wrinkles could not be observed on the surface revealed that the seeds lacked an outer cuticle of integument. Only occasionally did some seeds yield the outer cuticle of the integument upon maceration. Such seeds often also enclosed a hollow mud-filled interior inside the outer cuticle of the integument, as the 3 inner membranes seemed to have disintegrated as a result of fossilisation. In many dry specimens, it is difficult to distinguish the micropylar end from the chalazal end, as both ends exhibit a shallow depression. The micropylar canal is almost invisible in dry seeds, but its features become clearly visible in semitransparent seeds that have been subjected to maceration in Schulze's solution. The micropylar canal is short, straight, but dilated in the form of a funnel at the apical end (Figures 2 and 3). On rare occasions, the micropylar canal was not found to be straight and protruding outside (Figure 2), but was rather seen bent downwards over the nucellus and pollen chamber. At the mouth of the funnel, clusters of striated *Rugapites* pollen grains are found. Additionally, near the seed base, many pollen grains are also found sticking to the inner cuticle of the integument. Sometimes isolated pollen grains are found inside the micropylar tube.

The short micropylar canal, usually sunken in a pit in seeds of *R. minuta*, seemed to have hindered pollination. To overcome this handicap, the apical end of the micropylar canal presumably became dilated so that the entrapping of larger-sized pollen clusters besides the solitary ones could be facilitated. Such a modification appears to have been an adaptive device for successful pollination.

Besides *Rugapites* pollen grains, bisaccate and trisaccate pollen grains are sometimes also found sticking to the inner cuticle of the integument, but not inside the micropylar canal (Figure 3). These pollen grains have reticulately ornamented corpus and sacci and are very few in number compared to *Rugapites* grains. Therefore, they have been regarded as foreign pollen grains that were not pollinating *R. minuta* ovules.

The micropylar canal opened below into the pollen chamber, which formed a disc-like depression in the nucellus. It contains clusters as well as isolated pollen grains of the *Rugapites* type (Figure 3). While the isolated pollen grains appeared spheroidal in shape, those in clusters appeared to be ellipsoidal. The nucellar membrane is granular, appearing less

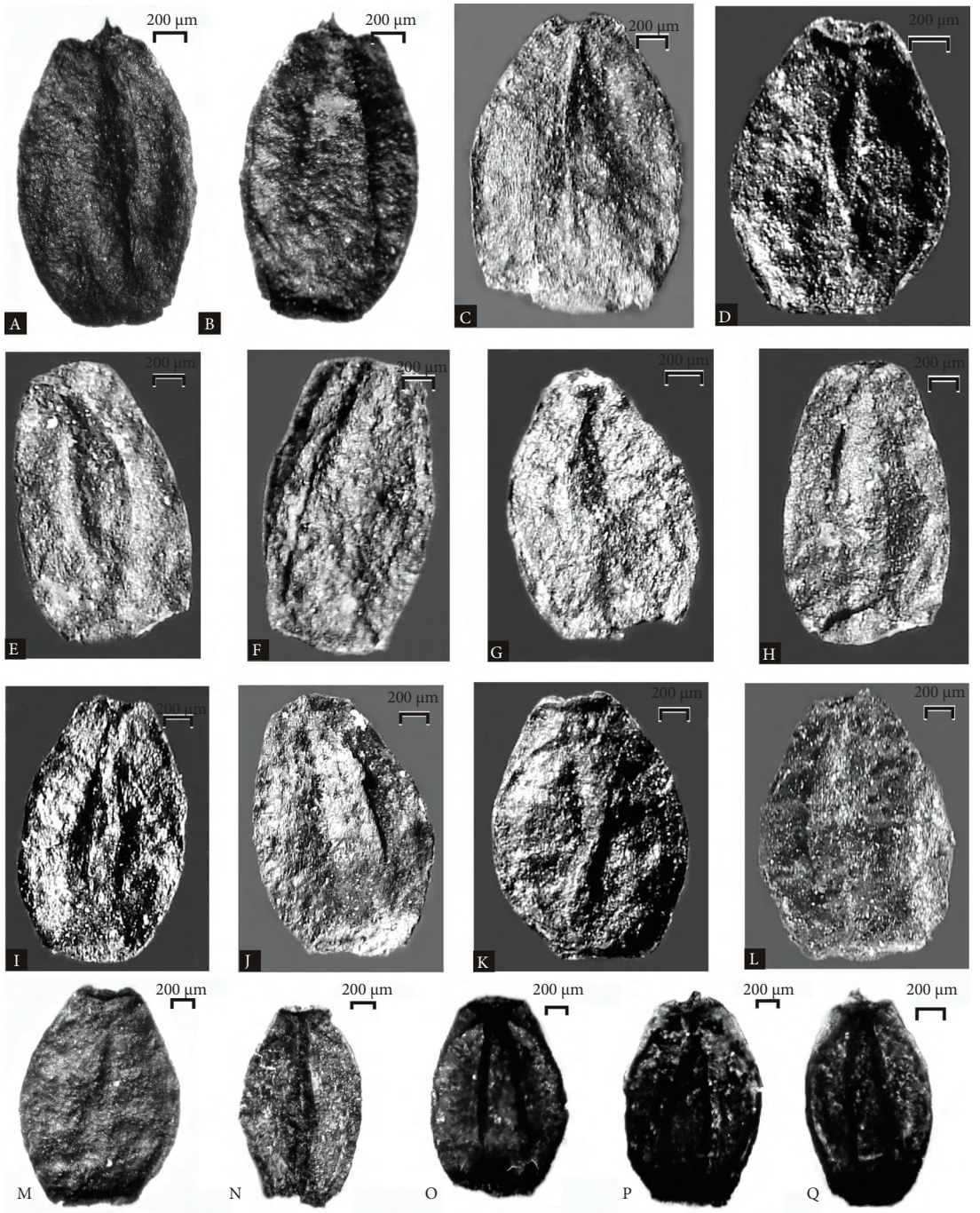

Figure 2. External features of *Rugaspermum minuta* sp. nova.

A and B. Obverse and reverse sides of a compressed seed showing lateral ridge on the surface, a shortly mucronate micropyle, and a chalazal hole. Holotype Slide No. 53,311.

C-M. Compressed seeds showing a lateral ridge, rectangular depression at the micropylar end, and longitudinal surface striations. Slide Nos. 53,318, 53,319, 53,314, 53,317, 53,328, 53,327, 53,320, 53,321, 53,325, 53,324, and 53,315.

N and O. Macerated seeds showing rectangular micropylar end depressions and lateral ridges. Slide Nos. 53,333 and 53,332.

P and Q. Two macerated seeds showing lateral ridges and slightly protruding short, oblique micropylar tubes arising from the centre of a rectangular depression. Slide Nos. 53,329 and 53,311.

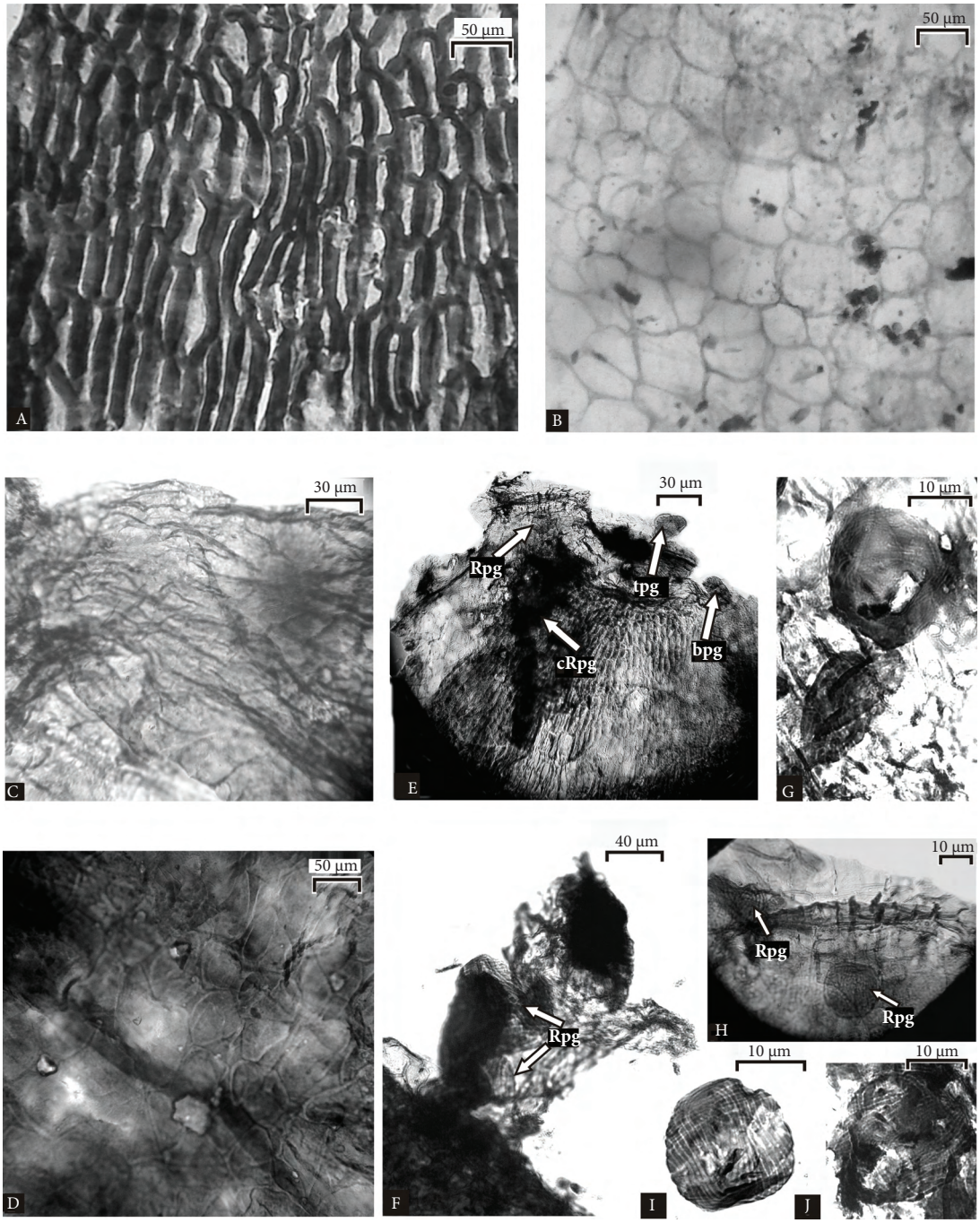

Figure 3. Cuticular features of *Rugaspermum minuta* sp. nova.

A. Outer cuticle of integument showing thick-walled, rectangularly elongated cells (Holotype Slide No. 53,311).
B. Inner cuticle of integument showing polygonoid thin-walled cells (Slide No. 53,311).
C. Micropylar end of seed showing nucellar cuticle (Slide No. 53,311).
D. Thick, dark cuticle of megaspore membrane showing faint polygonal cell outlines (Slide No. 53,311).
E. Short micropylar tube of another macerated seed showing a single striate *Rugapites*-type pollen grain above and a cluster of the same below. Bisaccate and trisaccate pollen grains can also be seen sticking to other cuticles (Slide No. 53,319).
F. Magnified view of micropylar canal of holotype showing pollen grains inside (Slide No. 53,311).
G. Magnified view of 2 *Rugapites* pollen grains teased out of the micropylar canal in a macerated seed (Slide No. 53,319).
H. Magnified view of a portion of seed micropyle showing 2 *Rugapites*-type pollen grains (Slide No. 53,319).
I. More magnified view of the pollen grain teased out of the micropylar canal (Slide No. 53,319).
J. Another *Rugapites*-type pollen grain from a pollen cluster (Slide No. 53,319).

Rpg: *Rugapites*-type pollen grain, bpg: bisaccate pollen grain, tpg: trisaccate pollen grain, cRpg: cluster of *Rugapites*-type pollen grains.

delicate in comparison to the inner cuticle of the integument. It shows obscure to clear impressions of thin-walled rectangularly elongated cells with straight to slightly sinuous lateral and oblique cross walls (Figure 3).

The megaspore membrane of the new seeds is massive and seems to occupy almost the entire seed area, except for a small fraction at the apical end. The surface appears smooth to granular and the cell outlines are faintly visible on account of the dark colour. Wherever visible, the cell outlines appear polygonal, showing moderately thickened straight cell walls and a wide cell lumen. No archegonia were visible at the apical end of the megaspore membranes (Figure 3).

Comparison and discussion

Rugaspermum minuta sp. nova differs from all previously described seeds from the Nidpur beds, like *Savitrispermum*, *Nidispermum*, *Pyriformispermum*, *Rotundaspermum*, *Pantiaspermum*, *Delevoryaspermum*, *Tayloriaspermum*, *Cupolaspermum*, *Konaspermum*, *Sahnispermum*, *Urceolaspermum*, and *Chaturvedeacarpon* (Pant & Basu, 1977; Manik, 1987; Srivastava & Manik, 1990, 1993, 1996; Srivastava et al., 2001) in having a small size, an oval to barrel shape, and a lateral ridge running from the apex to the base on both the obverse and reverse sides of the seed.

In comparing it with previously reported species of *Rugaspermum* (Table), we find the new species resembling the type species *R. insigne* as well as *R. media* and *R. obscura* in being pollinated by the same striate, unwinged, *Rugapites*-type pollen grains and in having a wrinkled surface. It differs, however, in having a small size, a barrel shape, and a rectangularly ridged micropylar end, and in lacking a distinct constriction demarcating the seed body from the chalazal end. Besides the above, just as the trichome morphology of the fruit wall has often been used as a character to distinguish various species of the extant members of Brassicaceae *Erysimum* Mutlu (2010), different types of papillae present on the cells of the outer integument of the seed were used to differentiate various species of the seed genus *Rugaspermum* (Pant & Basu, 1977). The wrinkles on the seed coat in the new species *R. minuta* are, however, not formed by terminal papillae on the anticlinal walls of the transverse rows of cells of the outer cuticle of the integument, but are formed as a result of the uneven thickening of the anticlinal walls of the outer integument cells.

Moreover, the size of seeds of all earlier described species of *Rugaspermum* is relatively large compared to *R. minuta*, and their shapes are reportedly oval. Even the cuticular features of the outer integument of seeds showed variation in form and thickness. While the cuticles of both *R. insigne* and *R. media* were nonstomatiferous like those of *R. minuta*, the shape of the cells and the thickness of cell walls greatly varied. In *R. insigne*, the cells were rectangularly elongated, having a terminal papilla, while in *R. media*, the cells were polygonal with a median papilla. Cells of *R. minuta* are nonpapillate.

In comparing *R. obscura* with *R. minuta*, the differences become more obvious. While the seeds of *R. obscura* have been described as being "urn"-shaped with a distinctly demarcated micropylar end, the seeds of *R. minuta* are oval to barrel-shaped with no clear demarcation of a micropylar or chalazal end. Even the cuticles of the outer integuments in both species showed significant differences. The cuticle is stomatiferous in *R. obscura*, but nonstomatiferous in the new species. Besides the presence and absence of stomata, the shape of the cells also varied. In *R. obscura*, cells are polygonal in shape and thin-walled, while in *R. minuta*, the cells are rectangularly elongated with very thick walls. Despite these differences, seeds of the new species, *R. minuta*, are being assigned to *Rugaspermum* on account of showing 2 important characters: occurrence of *Rugapites*-type pollen grains within the pollen chambers of seeds, and the seed surface having a wrinkled appearance.

The ridged and furrowed pollen grains of *Rugapites* pollinating *Rugaspermum* seeds are remotely comparable to the polyplicate pollen types of gnetophytes, which are believed to have pollinated the Cretaceous seeds of *Ephedra portugallica* and *E. drewriensis* (Taylor et al., 2009). *Rugaspermum* seeds also resembled the Cretaceous seeds in exhibiting remains of the ridged and furrowed exines of *Rugapites* pollen grains in the micropylar tube and pollen chamber of some seeds.

Incidentally, another pollen type, *Weylandites*

Table. Comparison of different species of Rugaspermum (Pant & Basu, 1977).

S. No.	Name of species	Size of seed in mm		Wrinkles	Cells of outer cuticle of integument	Stomata in outer cuticle of integument	Cells of nucellar cuticle	Megaspore membrane	Lateral ridge	Micropylar end
		Length	Width							
1.	***R. insigne***	1-2.5	1-2.2	Well marked	Longitudinally elongated. Surface nonpapillate. 46 µm × 13 µm. Wall 10 µm thick.	Absent	Elongated with slightly sinuous sides	Covering almost two-thirds or a major portion of lower half of seed.10 µm thick.	Absent	Broadly oval with a short micropylar beak
2.	***R. media***	2.5	2.0	Less marked	Isodiametric, polygonal, surface with a median papilla. 36 µm × 13 µm. Wall 4 µm thick.	Absent	Elongated with slightly sinuous sides.	Covering two-thirds of total seed. 7 µm thick.	Absent	Rounded
3.	***R. obscura***	2.8	2.4	Obscure	Isodiametric, polygonal, surface nonpapillate. 21 µm × 16.5 µm, Wall 3.5 µm thick.	Present	Short with more sinuous sides	Covering more than half of the total portion of seed area. 5 µm thick.	Absent	Constricted
4.	***R. minuta***	1-2.0	1-1.5	Less marked	Rectangularly elongated, surface nonpapillate. 63 µm × 15 µm Wall 13 µm thick.	Absent	Rectangularly elongated with slightly sinuous sides	Covering a major portion of seed area. 10 µm thick.	Present	Rectangularly ridged with a short, mucronate micropylar tube at centre

Bharadwaj & S.C.Srivast. 1969 (assigned to the sporae disperse), described from the same Nidpur Triassic beds, seemingly resembled *Rugapites* pollen grains in having a vertically, obliquely, or horizontally striated exine. Such pollen grains, in the opinion of Balme (1995), were contained within the micropylar canal and pollen chamber of *Rugaspermum* seeds. He further suggested that the pollen grains reported inside the macerated sporangia of *Rugatheca nidpurensis* D.D.Pant & Basu (1977) were also of the *Weylandites* type, as he was not convinced by the triradiate scar shown in the photomicrographs and figures of pollen grains of *Rugapites*. Balme (1995) therefore did not regard *Rugapites* as a new type of pollen grain. He further opined that the pollen of the *Weylandites* and *Rugapites* types were highly characteristic, and that *Weylandites* was widespread in the Gondwana Permian and often particularly common near the top of the system. The present authors, however, are convinced that the 2 pollen grains are distinct and that those found inside the micropylar canal and pollen chamber of *R. minuta* are undoubtedly of the *Rugapites* and not of the *Weylandites* type.

Regarding possible affinities of the seed genus *Rugaspermum*, no attached identifiable megafloral parts have been recorded so far from the Nidpur Triassic beds; until such time, only general conclusions can be made, such that the seeds were borne on a plant of gymnospermous affinity.

Conclusion

The new seeds have been assigned to the seed genus *Rugaspermum* D.D.Pant & Basu (1977) on account of their wrinkled appearance and the occurrence of the *Rugapites* (Pant & Basu, 1977) type of pollen grains inside their micropylar tube and pollen chamber. The earlier described species of *Rugaspermum* (*R. insigne*, *R. media*, and *R. obscura*) were reportedly pollinated by similar pollen grains and also had a wrinkled surface. *Rugapites* pollen grains were produced by the synangiate pollen organ *Rugatheca* D.D.Pant & Basu (1977), which was found associated with the earlier described species of *Rugaspermum* D.D.Pant & Basu (1977).

However, *R. minuta* seeds were not found in association with *Rugatheca* pollen organs, and they differ from the earlier described species in several features (Table). The *R. minuta* seed is smaller, it has an oval- to barrel-like shape, and the micropylar end shows a rectangular ridge enclosing a shallow depression, from the centre of which projects the micropylar tube. Besides this, the seeds also show a wide lateral ridge running from the base to apex on the obverse as well as reverse sides. Moreover, the outer cuticle of the integument has nonpapillate cells quite unlike the earlier described species, which show papillate epidermal cells. The wrinkled surface appearance in *R. minuta* seeds is due to the unevenly thickened anticlinal walls of transverse rows of epidermal cells of the outer integument and not the cell papillae.

Other details of the new seed are similar to the earlier reported species. Similar to in the earlier described species, the inner cuticle of the integument is free towards the micropyle but fused with the nucellar cuticle lower down. The nucellar apex also shows an excavated pollen chamber.

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