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Seed Structure and Germination Pattern of Some Indian Mangroves with Taxonomic Relevance

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ABSTRACT: Seed morphology and germination patterns of 17 halophytes belonging to 10 families of Sundarbans, India, were studied in view of their dispersal, rehabilitation and taxonomic interest. Fruits are mostly one seeded in the investigated taxa, except in *Acanthus ilicifolius*, *Excoecaria agallocha*, *Sonneratia apetala* and *Xylocarpus* spp. Seeds are inseparable from fruits in *Aegialitis rotundifolia*, *Aegiceras corniculatum*, *Avicennia* spp., *Nypa fruticans* and the investigated species of Rhizophoraceae. Propagules are mostly dispersed by tidal water. They have to float for some distance prior to establishment for a gradual adjustment of the young ones towards the saline environment. Viviparous germination occurs in all members of Rhizophoraceae, where seed germination takes place immediately after fertilization without any dormancy period. In this case the long hypocotyl comes out of the seed and ultimately from the fruit when the fruit is still attached with the mother plant. This phenomenon is considered as the most complex and highly evolved phenomenon in evolutionary line. In *Aegialitis rotundifolia*, *Aegiceras corniculatum*, *Avicennia* spp. and *Nypa fruticans*, germination occurs following an incipiently viviparous type where the hypocotyl pierces out of the seed coat but not from the exocarp at the time of dispersal. This incident should be defined more appropriately as cryptovivipary. On the basis of seed characters, an identification key was generated for easy identification of the dispersing units.

KEY WORDS: Cryptovivipary, Dispersal, Mangroves, Propagules, Seed morphology, Vivipary.

INTRODUCTION

Sundarbans (Fig. 1), the largest single block of mangrove forest in the world (approx. 8373 km^2) (Mandal & Ghosh, 1989) is now really at stake due to decades of unplanned exploitation of forest resources and excessive demographic pressure on the land. It is obvious, that dispersal and establishment of propagules are critical in mangroves owing to tidal influence, high salinity of water and soil and dynamic nature of the land formation. In addition, as there is no seed dormancy period and buried seed bank of these plants, detailed study on seed morphology, dispersal and germination patterns is essential to pave in the recent efforts for replenishment of this mangrove forest.

Plenty of works were published mainly on dispersal property (Rabinowitz, 1978a; Clarke, 1993; Clarke & Myerscough, 1993), seed predation (Smith *et al*., 1989; McKee, 1995a, b) and seedling dynamics (Rabinowitz, 1978b; Jimenez & Sauter, 1991; Ellison & Farnsworth, 1993). DeVogel (1980) classified the dicots on the basis of seedling morphology and germination pattern; he commented on the degree of specialization in Rhizophoraceae. Tomlinson (1986) provided an overview on mangrove seed morphology and emphasized on the family Rhizophoraceae. Rabinowitz (1978a) hypothesized that the size and buoyancy of mangrove propagules may contribute to differential dispersal and establishment pattern. Apart from

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Fig. 1. Sundarbans of West Bengal, India.

other biotic factors, establishment of mangrove propagules solely depend on the morphology of the dispersed units, which provide some useful clues for taxonomic identification of propagules (Martin & Barkley, 1968). In this work, detail documentation has been done on seed/propagule morphology and germination patterns of some dominant mangroves of Sundarbans in view of taxonomy and allied fields.

MATERIALS AND METHODS

Fruits/seeds of 17 mangrove taxa (including two monocots and 15 dicot species) belonging to 10 families were collected from well-identified plants of the Sundarbans swamps. Morphology and longitudinal hand sections of mature fruits/seeds were thoroughly observed by an Olympus stereoscopic microscope and camera lucida drawings were made. For Scanning Electron Microscopy, the seeds/propagules or parts of the propagules were fixed in 25% Glutaraldehyde and then passed through different grades of alcohol for dehydration. Following a treatment in ethyl acetate, the samples were made to Critical Point Dryness with liquid CO_2. The materials were then gold coated for electron microscopy in order to study the surface ornamentation. Description of the seeds was prepared according to Martin and Barkley (1968). Seeds, which are not viviparous, were germinated *in vitro* and studied. Each measurement is an average with standard deviation from 15 seeds of each species. An identification key to the genera, based on seed characters, was prepared for taxonomic relevance.

RESULTS

Shape, size, surface feature, cotyledon and endosperm characters, position of hilum and micropyle, germination patterns of seeds/propagules of 17 halophytes belonging to 10 families of Sundarbans, India are described below. In some mangroves, where the seeds are inseparable, the gross characters of fruits are considered together with seeds.

Acanthus ilicifolius L. (Acanthaceae)

Fruit capsule, 3-4 seeded, dehisces explosively along dorsiventral suture; seed ovate to obovate, length 1.44 ± 0.69 cm, weight 0.15 ± 0.04 g; testa flattened delicate, surface wrinkled (Figs. 4A-B), whitish green; hilum proximal, micropyle near the hilum, radical extruded; cotyledons exalbuminous, semi-succulent enclosing the minute plumule and plumular leaf primordia; germination epigeal (Figs. 2A, 3A & B).

Aegialitis rotundifolia Roxb. (Plumbaginaceae)

Fruit 1 seeded, elongated, longitudinally dehiscent capsule (Figs. 2B, 3F & G); length 7.15 ± 0.27 cm, width 0.44 ± 0.04 cm, weight 1.08 ± 0.07 g; testa thick, funicular tube attached to seed and enlarging hypocotyl, micropyle distal; cotyledons exalbuminous, inseparable, embedding the plumular bud; germination cryptoviviparous, i.e. the hypocotyl protrudes from the seed coat but not the pericarp.

Aegiceras corniculatum (L.) Blanco. (Myrsinaceae)

Fruit 1 seeded, longitudinally dehiscent, curved capsule with acute apex and persistent calyx (Figs. 2C, 3C-E), size 5.06 ± 0.39 x 0.41 ± 0.04 cm; seed weight 0.27 ± 0.02 g, seed coat hard, brown, hairy with placental remains attached to mature seed coat (Figs. 4C-E), micropyle proximal, cotyledons exalbuminous, inseparable, embedding the plumular bud; germination cryptoviviparous.

Avicennia alba Blume (Avicenniaceae)

Fruit 1 seeded, leathery capsule; seed cordate, tapering towards apex forming extended beak (Fig. 3I), size 3.14 ± 0.42 x 1.28 ± 0.36 cm, weight 1.80 ± 0.21 g, blackish green, testa thin, papery; micropyle proximal; cotyledons unequal, folded, one abaxial and another adaxial to the plumular axis, succulent; exalbuminous; germination cryptoviviparous, radicle comes out of the seed coat.

Avicennia marina (Forsk.) Vierh. (Avicenniaceae)

Fruit 1 seeded leathery capsule, seed rounded and shortly beaked (Fig. 2D), size 2.7 ± 0.63 x 2.3 ± 0.8 cm, seed weight 1.63 ± 0.13 g, grayish green, testa thin and papery; micropyle proximal; cotyledons unequal, one abaxial and another adaxial to the plumular axis, succulent, exalbuminous, germination cryptoviviparous (Fig. 3J).

Avicennia officinalis L. (Avicenniaceae)

Fruit 1 seeded, leathery capsule, seed globose, abruptly narrowed to form a short beak, size 2.3 ± 0.35 x 1.9 ± 0.48 cm, weight 2.9 ± 0.34 g, blackish green; testa fragentary; micropyle proximal; cotyledons folded, one abaxial and another adaxial to the plumular axis, succulent, exalbuminous; germination cryptoviviparous (Fig. 3H).

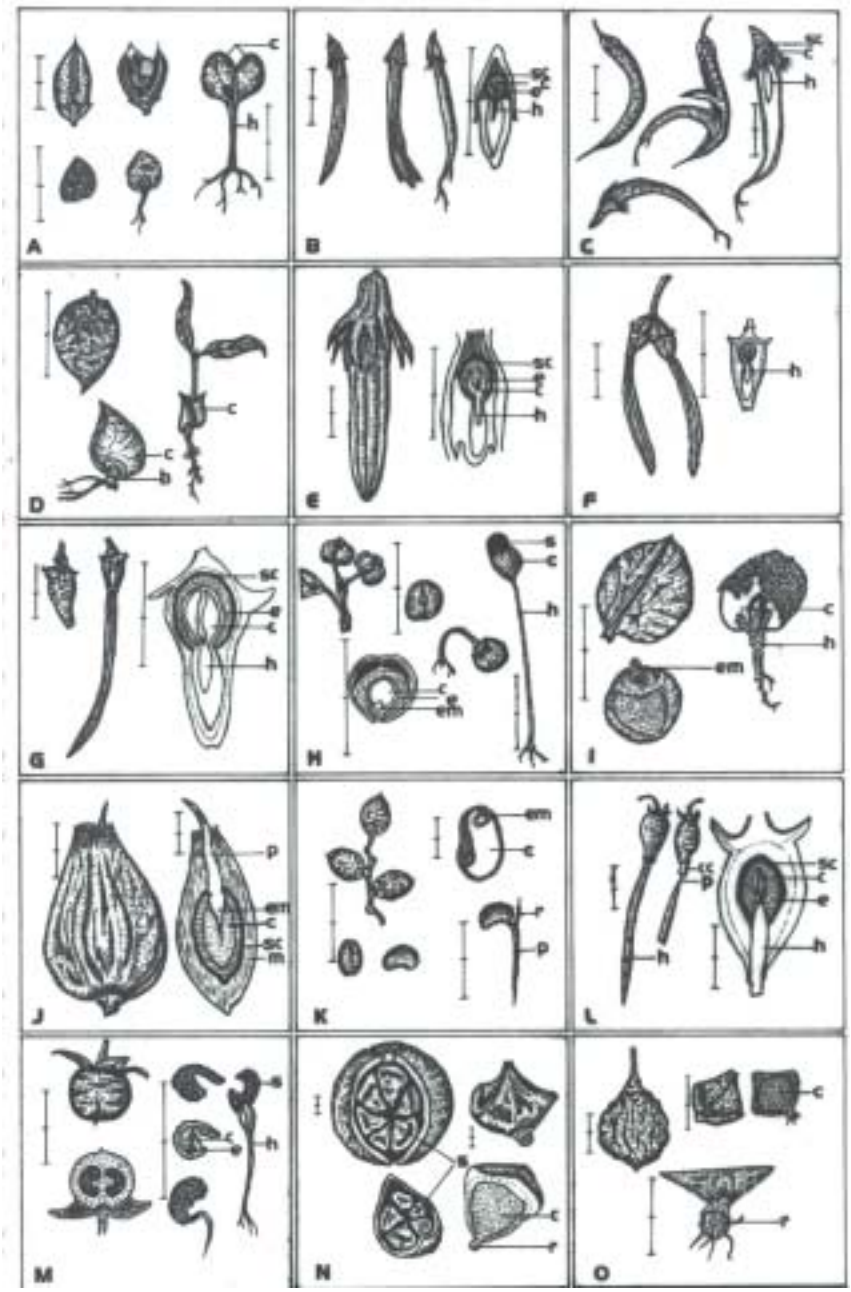

Fig. 2. A-O. Seeds / fruits, germination and longitudinal section (L. S.). A. *Acanthus ilicifolius*: fruit, seed and germinating seed. B. *Aegialitis rotundifolia*: fruit, emerging hypocotyl, L. S. of young fruit showing hypocotyl pierces out the seed coat. C. *Aegiceras corniculatum*: fruit, germinated fruit, L. S. showing hairy placental remains attached at the hypocotyl tip. D. *Avicennia marina*: fruit, folded cotyledons with emerging radical, young seedling with attached cotyledons. E. *Bruguiera gymnorrhiza*: fruit with hypocotyl, L. S. of young fruit showing emergent hypocotyl. F. *Ceriops decandra*: fruit with hypocotyl, L. S. of young fruit. G. *Ceriops tagal*: fruit, L. S. of young fruit. H. *Excoecaria agallocha*: fruiting twig, single seed, L. S. of seed, epigeal germination. I. *Heritiera fomes*: fruit, seed, germinating seed. J. *Nypa fruticans*: fruit with plumule. L.S. of fruit. K. *Phoenix paludosa*: fruiting head, single seed, L.S. of seed, germinating seed. L. *Rhizophora mucronata*: viviparous germination, L. S. of young fruit. M. *Sonneratia apetala*: fruit, L. S. of fruit, single seed, L. S. of seed, germinating seed. N. *Xylocarpus granatum*: fruit, seed, L. S. of seed. O. *Xylocarpus mekongensis*: fruit, single seed, L. S. of seed showing bulbous radical comes out. (c: cotyledon, cc: cotyledonary collar, e: endosperm, em: embryo, h: hypocotyl, m: mesocarp, p: plumule, r: radicle, s: seed, sc: seed coat). (Each scale bar represents one cm).

Bruguiera gymnorrhiza (L.) Lamk. (Rhizophoraceae)

Fruit 1 seeded with persistent obscure ribbed calyx; propagates with a long (15-20cm) ribbed hypocotyl with blunt apex, formed by the extending radicle following apical growth of the embryo; fruit remains attached to the propagating seedling (Figs. 2E, 3K & L); endosperms completely consumed by the developing embryo; among the eight ovules in the four-chambered ovary only one ultimately persists; micropyle distal, germination viviparous.

Ceriops decandra (Griff.) Ding Hou (Rhizophoraceae)

Fruit 1 seeded, conical, brown with persistent lenticulate calyx, blunt apex, surface rough, size 2.6 $\pm$ 0.13 x 1.2 $\pm$ 0.3 cm; germination occurs through the extending hypocotyl extruding from the seed and ultimately from the fruit; endosperms completely used up by the developing embryo; micropyle distal, germination viviparous (Fig. 2F).

Ceriops tagal (Perr.) Robinson (Rhizophoraceae)

Fruit 1 seeded conical, brown with persistent reflexed calyx, surface rough, apex pointed, size 3.8 $\pm$ 0.41 x 1.6 $\pm$ 0.27 cm; hypocotyl extruded from the seed and finally from the fruit; endosperms completely used by the developing embryo; micropyle distant; germination viviparous (Fig. 2G).

Excoecaria agallocha L. (Euphorbiaceae)

Fruit 3-lobbed schizocarp with persistent stigma, each of the 3 lobes release solitary seed; seed spheroidal, diameter 0.63 $\pm$ 0.12 cm, seed weight 0.09 $\pm$ 0.04 g., blackish-green; hard testa, surface finely reticulate; hilum mid-apical, micropyle ventral, below the hilum, rugulate (Figs. 4F & G); cotyledons cuneiform, radicle extruded, exalbuminous, germination epigeal (Figs. 2H, 3M - N).

Heritiera fomes Buch. – Ham. (Sterculiaceae)

Fruit 1 seeded with distinct ventral knob, and a transverse circular ridge, epicarp woody, mesocarp fibrous, endocarp hard; seed coat brown, papery, seed ovoid, size 3.58 $\pm$ 0.89 cm, weight 4.23 $\pm$ 0.8 g, cotyledons creamy-white, convex, succulent, radical directed ventrally, plumular bud grows upward with distinct articulation, reddish; micropyle ventral, exalbuminous, germination hypogeal; seeds being attached with the adult seedlings (Figs. 2I, 3O).

Nypa fruticans Wurmb. (Arecaceae)

Fruit one seeded angular, drupe; seed hard, dark brown, ellipsoid, adaxially grooved, exocarp smooth, mesocarp fibrous, endocarp thick; size 9.3 $\pm$ 1.08 x 4.8 $\pm$ 1.2 cm, weight 26.13 $\pm$ 1.32 g; hilum ventral; cotyledon one, haustorial, embryo conical, basal; endosperm with a centrally hollow region and totally consumed by the germinating embryo, micropyle apical, germination essentially epigeal, but incipient viviparous as germination initiates on the fruiting head with the protruding plumule before the fruit released (Fig. 2J).

Phoenix paludosa Roxb. (Arecaceae)

Fruit one seeded drupe, shining orange, turns black when riping, mesocarp fleshy; seeds cartilaginous, dark brown, surface with distinct ridges and furrows (Fig. 4H & I), ellipsoid; size 1.2 $\pm$ 0.62 x 0.55 $\pm$ 0.05 cm, weight 0.73 $\pm$ 0.13 g, hilum ventral; cotyledon single, haustorial, consumed during embryo germination; embryo apical, during germination the terminal part of the embryo shoot remains concealed within the sheathing part of the cotyledon; endosperms stony; micropyle mid-apical; germination hypogeal (Figs. 2K, 3P).

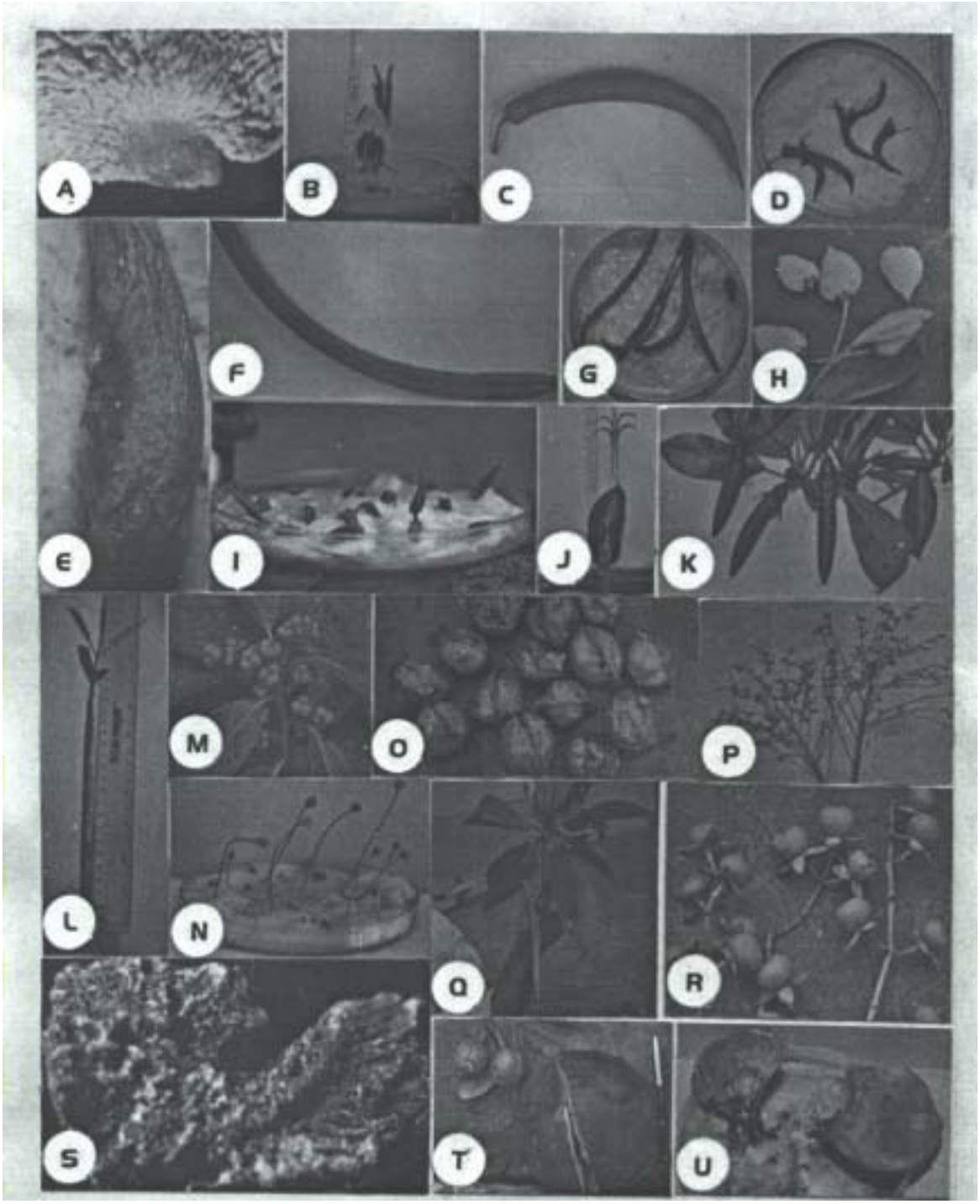

Fig. 3. A-U. Photographs of some seeds/fruits. A & B. *Acanthus ilicifolius*, A. portion of seed surface, B. germinating seed. C-E. *Aegiceras corniculatum*, C. fruit, D. germinating fruit, E. embryonic tip, hilum prominent. F & G. *Aegialitis rotundifolia*, F. fruit, G. germinating fruit. H. fruits of *Avicennia marina*. I. germinating fruit of *Avicennia alba*. J. young seedling attached with cotyledons of *Avicennia officinalis*. K & L. *Bruguiera gymnorrhiza*, K. fruits, L. seedling with long hypocotyl. M & N. *Excoecaria agallocha*, M. fruiting twig, N. epigeally germinating seed with long hypocotyl, seed coat attached at the tip. O. fruits of Heritiera fomes. P. fruiting head of *Phoenix paludosa*. Q. viviparously germinating fruit of *Rhizophora mucronata*. R & S. *Sonneratia apetala*, R. fruiting bunch, S. single seed. T & U. *Xylocarpus granatum*, T. fruit, U. germinating seed.

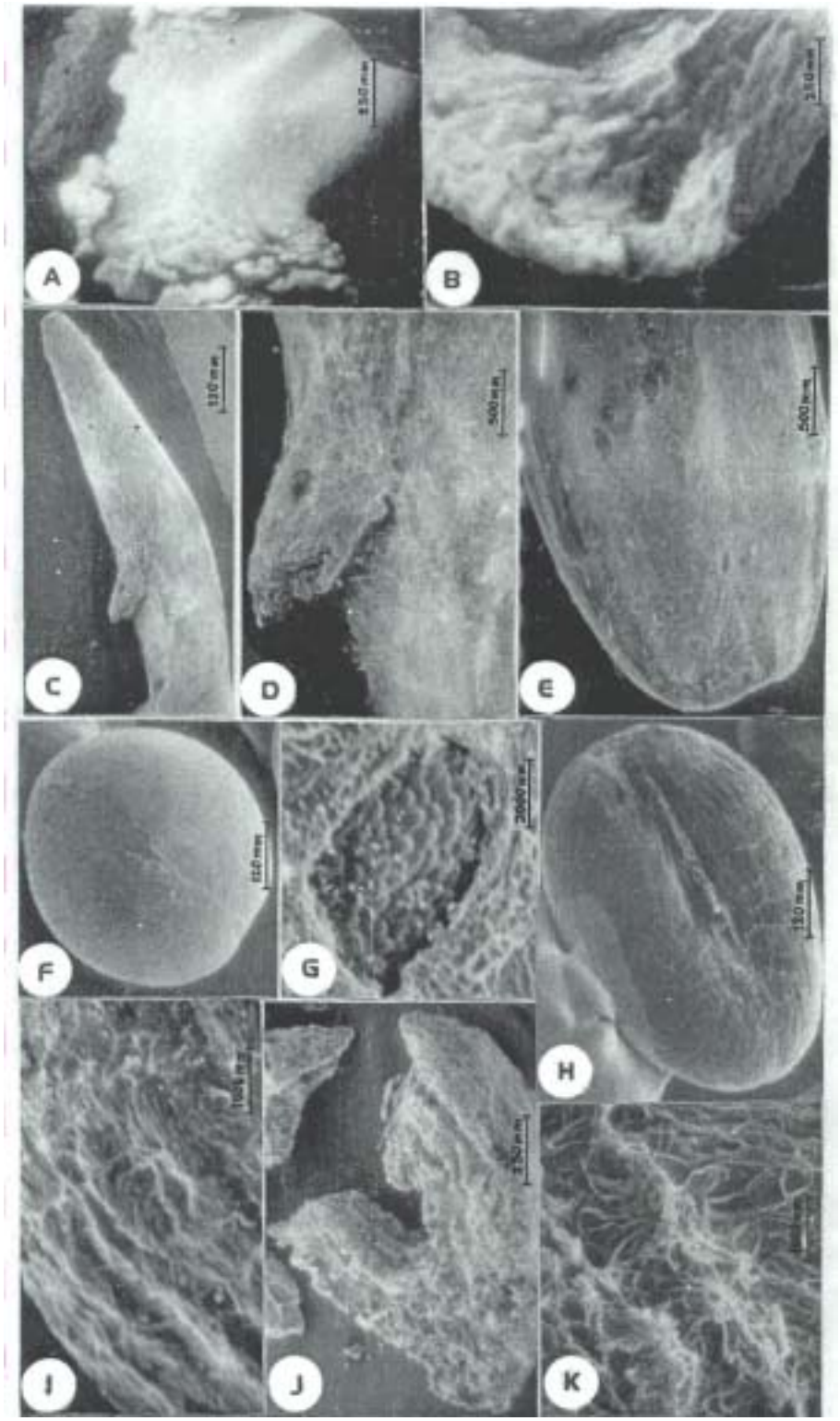

Fig. 4. A-K. SEM of some mangrove seeds. A & B. *Acanthus ilicifolius*, A. seed portion with hilum, B. portion of seed surface. C-E. *Aegiceras corniculatum*, C. embryonic tip of the fruit, D. embryonic tip, hilum with hairy placental remains, E. rooting tip of the hypocotyl. F & G. *Excoecaria agallocha*, F. single seed, G. micropylar region. H & I. *Phoenix paludosa*, H. single seed, I. portion of seed surface. J & K. *Sonneratia apetala*, J. single seed, K. portion of areolated seed surface.

Rhizophora mucronata Lamk. (Rhizophoraceae)

Fruit one seeded with persistent reflexed woody calyx, ovate-oblong, brown, pericarp leathery, size 4.0 ± 0.37 x 2.6 ± 0.52 cm; germination occurs by extension of the hypocotyl immediately after fertilization; cotyledons fused to form a tubular collar that comes out of the fruit at maturity before abscission of the seedling; hypocotyl fusiform and warty; endosperms present at early stage of embryo development, germination viviparous (Figs. 2L, 3Q).

Sonneratia apetala Buch. - Ham. (Sonneratiaceae)

Fruit berry with persistent leathery calyx, green with numerous seeds; seeds compactly arranged in 6 - 8 locules within the fleshy pulp of the placenta, yellowish, mostly "U" or "V" shaped, surface irregularly aeriolated (Figs. 4J & K); size 0.88 ± 0.07 x 0.65 ± 0.09 cm, weight 0.09 ± 0.02 g, hilum middle i.e. within the invaginated portion of the seed; micropyle position obscure, radicle emerges from any one arm of the seed; exalbuminous, germination epigeal (Figs. 2M, 3R & S).

Xylocarpus granatum König. (Meliaceae)

Fruit woody capsule, dehisces along four distinct longitudinal furrows, seeds 8-12, arranged compactly, pyramidal, reddish brown, size 8.81 ± 1.15 x 7.89 ± 1.7 cm, weight 77.06 ± 3.0 g; testa corky, smooth; cotyledon undifferentiated, haustorial, exalbuminous; radical protrudes with numerous root initiating sites; hilum proximal, micropyle distal; germination hypogeal and cotyledons not exposed; seed remains attached to the adult seedling (Figs. 2N, 3T & U) .

Xylocarpus mekongensis Pierre (Meliaceae)

Fruit woody capsule, ovoid, pericarp hard, surface irregular; seeds 12-16, compactly arranged, pyramidal, reddish brown, size 3.82 ± 0.08 x 2.94 ± 0.91 cm, weight 7.78 ± 1.2 g; testa smooth and corky; cotyledons undifferentiated, haustorial, exalbuminous; radicle protrudes with numerous root-initiating sites; hilum proximal, micropyle distal; germination hypogeal and cotyledons not exposed; seed remains attached to the adult seedling (Fig. 2O).

Identification key to the investigated genera

1A. Seed monocotyledonous 2
1B. Seed dicotyledonous 3
2A. Fruit with thin mesocarp, seed elliptic ..... Phoe*nix*
2B. Fruit with fibrous mesocarp, seed ellipsoid ..... *Nypa*
3A. Seed germination viviparous 4
3B. Seed germination otherwise 6
4A. During propagation, hypocotyl separated from mother plant, along with the fruit attached to its tip ..... *Bruguiera*
4B. During propagation, hypocotyl separated from the fruit, while the latter is still attached to mother plant 5
5A. Fruit relatively large, with persistent tertrahedral calyx ..... *Rhizophora*
5B. Fruit relatively small, with persistent pentamerous calyx ..... *Ceriops*
6A. Seed germination incipient viviparous (cryptoviviparous) 7
6B. Seed germination otherwise 9
7A. Hypocotyl reduced, cotyledon two-folded ..... *Avicennia*
7B. Hypocotyl 3-6 cm long 8
8A. Hypocotyl smooth, tip needle-like ..... *Aegiceras*
8B. Hypocotyl with distinct 5/6 longitudinal ridges, tip blunt ..... *Aegialitis*

9A. Pericarp hard, brown colour, wavy with longitudinal slit ……...…… 10
9B. Pericarp soft, greenish, smooth ……...……..... 11
10A. Single seeded, spherical, brown papery seed coat ……... *Heritiera*
10B. 8-12 seeded, pyramidal, leathery seed coat ……..... *Xylocarpus*
11A. Seed numerous, minute,'U' to 'V' shaped, surface areolate ……...…….. *Sonneratia*
11B. 3-4 seeds per fruit ……...…… 12
12A. Seeds spherical, smooth, blackish-brown colour ……...….. *Excoecaria*
12B. Seed disk shaped, wrinkled, whitish-green colour ……...…... *Acanthus*

DISCUSSION

Seeds are explosively released from the capsule in *Acanthus ilicifolius* and *Excoecaria agallocha*. The large woody capsule of *Xylocarpus* dehisces in the parent tree to release corky, pyramidal seeds. Calyx remains attached for some time with the dispersing green berry of *Sonneratia apetala* and small angular seeds are released following decay of the fruit pulp. In *Heritiera fomes*, single seeded capsule with fibrous epicarp is released from the mother plant and dispersed by tidal influence; the epicarp and the brown papery mesocarp break prior to seed germination. *Nypa fruticans* also has leathery epicarp with fibrous mesocarp that helps much for initial floating and dispersal of the propagules. In all the cases, initially the propagating agent has to float in saline water and ultimate establishment occurs through seed.

In *Aegialitis rotundifolia, Aegiceras corniculatum, Avicennia spp.* and *Nypa fruticans* propagation occurs by mature fruits and there is hardly any seed dormancy period after fertilization. In *Aegialitis* and *Aegiceras*, the embryo germinates within the fruit and the hypocotyl comes out of the seed coat but it does not pierce the pericarp; instead, the pericarp splits during establishment. In *Avicennia*, the radicle pierces the seed coat, but not the pericarp during dispersal. In *Nypa*, embryo germination initiates on the fruiting head with the protruding plumular part before the fruit is released from the mother plant. In members of Rhizophoraceae (*Bruguiera, Ceriops* and *Rhizophora*) propagules are dispersed with a long germinating hypocotyl separated from fruit, leaving the latter attached to the mother plant, except in *Bruguiera*, where fruit is abscised along with the hypocotyl. In *Rhizophora* and *Ceriops*, cotyledons entirely fuse to form a cylindrical collar like structure exposed from the fruit at maturity.

Dispersal and establishment of seeds or propagules are the important parts in the life cycle of all seed plants, but it rendered difficult in case of mangroves as they grow in variable, unstable, highly saline environment and mostly in tidal influenced area. As such, all mangrove propagules should have some ability to float, at least initially for some time. In some mangroves, vivipary as a niche property allows floating of seedlings until proper conditions for establishment (McMillan, 1971). As the mangrove propagules have to establish themselves on unstable variable substrate, length of the seedlings promotes establishment by extending hypocotyl before the seeds are dispersed. A comparative explanation from morphological, ecological and physiological viewpoints seems important to explain this phenomenon in evolutionary terms (Juncosa 1982). According to Joshi *et al*. (1972), high salt concentration may have some deleterious effects on the young embryo, so that most of the propagules spend some time in saline water before establishment, and there is a gradual adjustment in the saline condition. Juncosa (1982) pointed out that vivipary is a simple consequence of the amplification of the normal "torpedo" stage during embryo development by the extended growth of the hypocotyl. Thus vivipary is a modified pattern of epigeal germination that can be

considered as a highly evolved phenomenon among the different types of germination within mangroves. Viviparously germinating seedlings are mostly dependent for nutrition on its mother plant (Pannier & Pannier, 1975, Bhosale & Sindhu, 1983). This stage remains constant until the seedlings are dropped and develop their own root system from the apical (*Bruguiera*) or sub-apical (*Ceriops, Rhizophora*) part of the hypocotyl.

McMillan (1971) pointed that the black mangrove (*Avicennia germinans*) germinates viviparously. Ng (1978) considered the germination pattern in Rhizophoraceae as “Durian type" in his four groups of seedling types on the basis of morphological characters, where the hypocotyl is extended and the cotyledon is raised above the ground level. But in reality, this phenomenon is lacking in Rhizophoraceae. Hence DeVogel (1980) classified it as a separate group “Rhizophora type”; he included *Aegiceras* in this group. According to him, *Avicennia* is placed under Sloanea type/sub type 2a; first development of a shoot with scales are recorded in *Heritiera* (Helicopter type/sub type 6a); *Xylocarpus* has food storing haustorial cotyledons and small subterranean hypocotyl (Horsfieldia type/sub type 7a) and *Sonneratia* and *Excoecaria* are included in the most common type Macaranga type (type 1). *Aegiceras, Aegialitis* and *Avicennia* show a much different type of seed germination as described in DeVogel's (1980) classification and have much similarity among them, which lead to assemble them in a separate group where seed germination is incipiently viviparous. Tomlinson (1986) considered them as “cryptoviviparous”, a more appropriate term than the previous one.

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印度紅樹林的種子構造與發芽類型及其在分類學上的關係

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摘　　要

本文研究印度 17 種 (隸屬於 10 科) 鹽生植物的種子形態與發芽類型，並探討其傳播、復育及分類上之意義。在研究的物種中，除爵床 (*Acanthus ilicifolius*)、土沉香 (*Excoecaria agallocha*)、海桑 (*Sonneratia apetala*) 及木果楝 (*Xylocarpus* sp.) 外，果實均只含一種子。有些種子是無法與果實分開的，譬如藍雪科的一種紅樹林植物 (*Aegialitis rotundifolia*)、桐花樹 (*Aegiceras corniculatum*)、海茄冬 (*Avicennia* sp.)、水椰 (*Nypa fruticans*) 以及研究的所有紅樹科的物種。這些物種的繁殖體多由潮水所傳播，在定根之前需先漂流相當的距離以逐漸適應鹹水的環境。所有的紅樹科植物均有胎生苗的特性，受精後種子不經休眠逕自萌芽。因此種子還附在母株時，其下胚軸即由種子及果實中延生出來，這種特性在演化的途徑上是較為複雜及特殊的。在傳播時，藍雪科植物、桐花樹、海茄冬及水椰的初生胎生苗，其下胚軸僅穿過種皮而保留在果皮內，這種狀況可視為隱藏式胎生現象。根據種子的特徵，本文還提供檢索表作為鑑別物種之用。

關鍵詞：隱藏式胎生、散佈、紅樹林、繁殖體、種子形態、胎生。

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