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Review Article

The genus *Isoetes* from India: An overview

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Abstract

The information regarding the Indian quillwort is reviewed herewith to highlight the taxonomy, history, distribution, phytogeography, morphology, phenology, chromosome count, numerical taxonomy and present taxonomic scenario of Indian species. Authors also reviewed the opinions of different researchers on doubtful species of Indian *Isoetes*.

Keywords

Quillworts; Merlin's grass; Lycopsid; distribution; taxonomy; cytology

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Introduction

The genus *Isoetes* L., is an interesting and unique pteridophyte, popularly known as “quillworts or Merlin’s grass”. The Latin meaning is a small house-leek, for an annual plant (Plinius) while it is derived from two Greek words viz., *isos* “equal” and *etos* “a year” referring to the evergreen species or to the submerged species. It is considered as the most primitive lycopods and their presence on the planet is known since Triassic period (1). It is perennial, herbaceous, heterosporous pteridophyte, found growing in a variety of aquatic habitats. About 300–350 species are distributed in world, of which 18 species, 1 subspecies and 4 varieties have been reported from India (2). All Indian species or infraspecies are identified on the basis of velum characters, megaspore ornamentation and recent few species are on the basis of chromosome counts (3,4).

Total 23 species viz. *Isoetes bilaspurensis* Panigrahi, *I. coromandeliana* L. f., *I. coromandeliana* subsp. *thanensis* Shukla, S.K. Singh, P.K. Shukla,

N.K. Dubey, H. Khanam & G.K. Srivast., *I. debii* S. C. Sinha, *I. divyadarshanii* P. K. Shukla, G. K. Srivast. & S. K. Shukla & P. K. Rajagopal, *I. dixitii* Shende, *I. indica* D. D. Pant & Srivast., *I. indica* var. *harotiensis* Bhardwaj & Gena, *I. fuchsii* Goswami & U. S. Sharma, *I. mahadevensis* G. K. Srivast., D. D. Pant & P. K. Shukla, *I. mirzapurensis* Panigrahi and Dixit, *I. panchganiensis* K. Srivast., D. D. Pant & P. K. Shukla, *I. panchganiensis* var. *kemangundiensis* G. K. Srivast., D. D. Pant & P. K. Shukla, *I. panchananii* D. D. Pant & G. K. Srivast., *I. panchananii* var. *pachmarhiensis* D. D. Pant & G. K. Srivast., *I. pantii* Goswami & Arya, *I. pantii* var. *hybrida* Goswami, *I. rajasthanensis* Gena & Bhardwaj, *I. reticulata* Gena & Bhardwaj, *I. sampathkumaranii* L. N. Rao, *I. sahyadrii* Mahable and *I. tuberculata* Gena & Bhardwaj, *I. udupiensis* P. K. Shukla, G. K. Srivast., S. K. Shukla & P. K. Rajagopal have been reported from India by earlier researchers. Amongst these, only four species viz., *I. coromandeliana* L.f., *I. dixitii*, *I. sahyadrii* and *I. udupiensis*, is accepted in annotated checklist of

pteridophytes of India – I (5). There are several species published by various authors that are yet to be recognised as independent species. Therefore, there is an urgent need to revise the *Isoetes* from India. The revision should be coupled with data on their ecology, phenology, spore morphology, cytology and molecular studies.

Taxonomic history of *Isoetes*

The name *Isoetes* was first introduced by Linnaeus (6) in his book “*Species Plantarum*”. However, earlier botanist had described similar plants under different generic name viz., *Marsilea*, *Calamaria* and *Subularia* (7). Linnaeus (6) had described the genus *Isoetes* as a seed bearing plant produces unisexual flower without calyx and corolla. He also mentioned that capsule was hidden in the basal portion of the leaf and having many seeds per capsule. However, his son Linnaeus filius (8) described a new species, i.e. *Isoetes coromandeliana*, from Coromandel Coast, Tamil Nadu. Thereafter, Reichenback (9) introduced the family Isoetaceae to include the genus *Isoetes*. Subsequently, Braun (10,11) published a series of paper on *Isoetes* from Germany, Australia and Sardinia. Motelay and Vendryes (12) described nearly 47 species of *Isoetes* in their publication “*Monographic der Isoeteae*”. Pfeiffer (13) also published a monograph on “Isoetaceae”, while “*Index Isoetales*” was published by Reed (7) and suggested nomenclatural changes in the genus *Isoetes*. Taxonomy and spore morphology of *Isoetes* from North Eastern America was investigated by Kott and Britton (14). In last few decades modern tools like rbcL, nuclear and chloroplast DNA sequences have been used to study the cytology, and Karyology of *Isoetes* (15,16,17).

As far as Indian *Isoetes* history is concerned, Linnaeus filius (8) was the first to describe a first species i.e. *Isoetes coromandeliana* from Coromandel Coast, Tamil Nadu. Later on Engelmann and Butler (18) reported the occurrence of *Isoetes* from Indian Territory. Thereafter, McCann (19) published a note on *Isoetes* of Bombay Presidency. Subsequently, Mahabale (20) described a new species *I. sahyadrii* (misspelled *I. sahyadriensis*) from Table-Land Plateau of Panchgani, Maharashtra, *I. sampathkumaranii* from Baba Budangiri hills, Karnataka by Rao (21), *I. dixitii* (misspelled *I. dixitei*) from Table-Land Plateau of Panchgani by Shende (22). Pant and Srivastava (23) reviewed the genus *Isoetes* in India and described two more new species i.e. *I. panchananii* and *I. indica* on the basis of velum character and morphology of plants and spores. Goswami and Arya (24) described another species as *I. pantii* from Madhya Pradesh.

Panigrahi (25) second time reviewed taxonomy of Indian *Isoetes* and described two more new species, viz. *I. bilaspurensis* and *I. mirzapurensis*. Subsequently, additional species, viz. *I. tuberculata*, *I. reticulata* and

I. rajasthanensis were described by Gena and Bhardwaj (26) from Rajasthan. Vasudeva and Bir (27) had given an account of Isoetaceae of Pachmarhi Hills, central India. Sinha (28) described another new species i.e. *I. debii* from Manipur, India. Srivastava *et al.* (29) also published review of the genus *Isoetes* in India, while Ghosh and Ghosh (30) published another review in a book entitled “Floristics, Diversity and Conservation Strategies in India Vol. I published by Botanical Survey of India. They reported 16 species of *Isoetes* distributed in various parts of India. However, Fraser-Jenkins (31) merged majority of species of Indian *Isoetes* into *Isoetes coromandeliana*. Later on Srivastava (3) had given an account of morphology and taxonomy of Isoetaceae in India and reported 15 species, 3 subspecies and 3 varieties. He divided all the Indian species into 3 complexes viz., *I. coromandeliana*, *I. dixitii* and *I. panchananii* complex.

A new species *Isoetes fuchsii* is described by Bhu *et al.* (32) from Madhya Pradesh and stated as an intermediate form of *I. coromandeliana* and *I. sampathkumaranii*. Shukla *et al.* (33) studied distribution, endemism and species radiation of quillworts in India. Subsequently Shukla *et al.* (34) described two new species viz., *I. udupiensis* and *I. divyadarshanii* from Western Ghats of India. Patil *et al.*, (4) working on pteridophyte diversity of Northern Western Ghats reported 8 species of *Isoetes*, from which *I. indica* was documented as new distributional record for Western Ghats, India. Recently, a new subspecies *I. coromandeliana* subsp. *thanensis* was published by Shukla *et al.* (2) from the Saurashtra region of the Gujarat state.

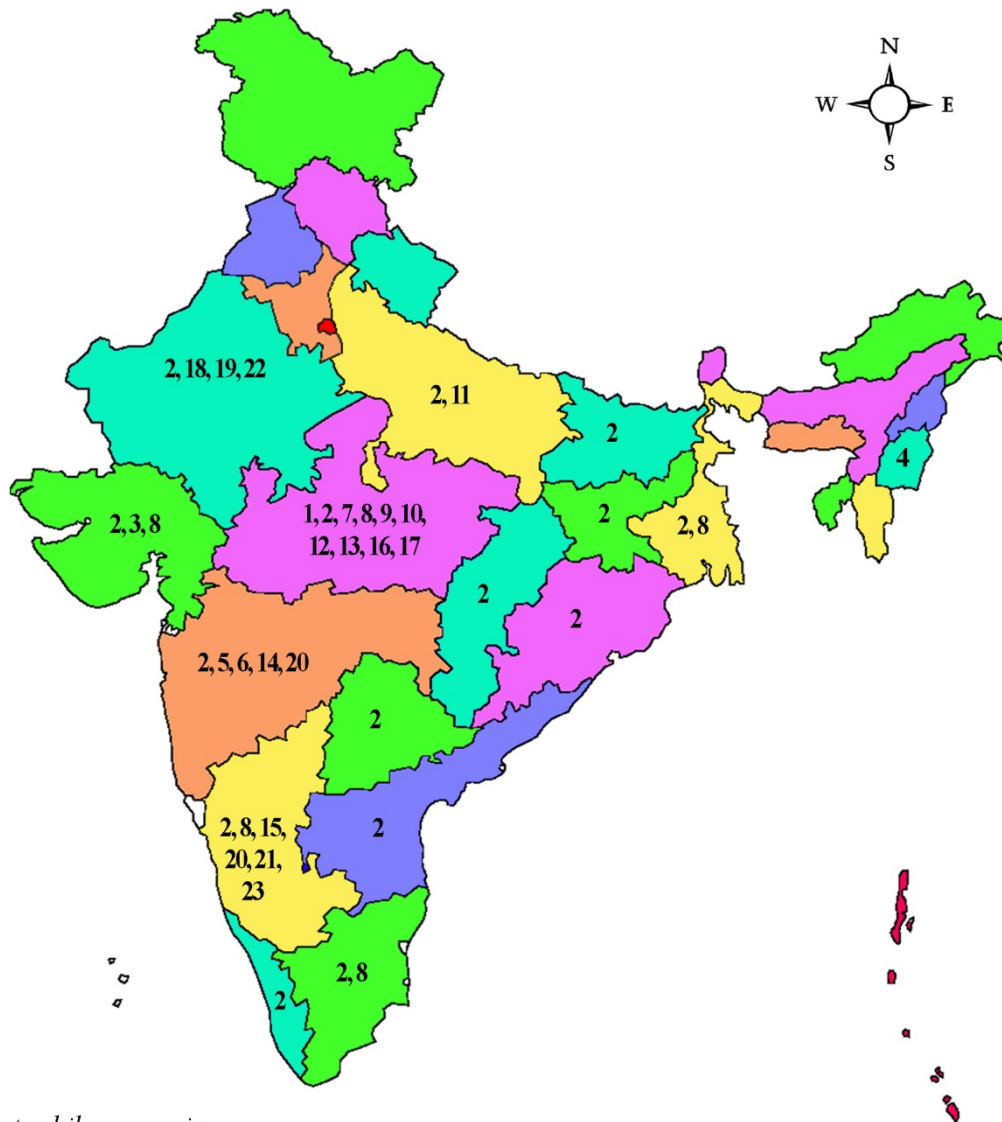
Distribution of the *Isoetes* in India

The genus *Isoetes* is a semi-aquatic species, one-two or more than two species are recorded from almost all the states of India (excluding few north Indian states). There are few reports on the distributional studies (32,35). Analysis of species distribution indicates that *Isoetes coromandeliana* is the most common species and it is recorded from almost all the states of India (except some Northern States). After *I. coromandeliana*, *Isoetes indica* is another common species that has been more frequently reported from different states viz., Madhya Pradesh, Maharashtra, Karnataka, Gujarat, West Bengal and Tamil Nadu (3) while others species have their restricted distribution.

A single species *Isoetes debii* is reported from North-East India and none of other species are reported from this region. Similarly, *I. mirzapurensis* is reported from Mirzapur (Uttar Pradesh).

Regarding endemism, species like *Isoetes rajasthanensis*, *I. reticulata* and *I. tuberculata* are endemic to Rajasthan (India). Similarly, few species viz., *I. panchananii*, *I. pantii*, *I. bilaspurensis*, *I. fuchsii*, *I. mahadevensis* and few

Distribution of genus *Isoetes* L. from India



1. *Isoetes bilaspurensis*
2. *Isoetes coromandeliana*
3. *Isoetes coromandeliana* subsp. *thanensis*
4. *Isoetes debii*
5. *Isoetes divyadarshanii*
6. *Isoetes dixitii*
7. *Isoetes fuchsii*
8. *Isoetes indica*
9. *Isoetes indica* var. *harotiensis*
10. *Isoetes mahadevensis*
11. *Isoetes mirzapurensis*
12. *Isoetes panchananii*
13. *Isoetes panchananii* var. *pachnarhiensis*
14. *Isoetes panchganiensis*
15. *Isoetes panchganiensis* var. *kemangundiensis*
16. *Isoetes pantii*
17. *Isoetes pantii* var. *hybrida*
18. *Isoetes rajasthanensis*
19. *Isoetes reticulata*
20. *Isoetes sahyadrii*
21. *Isoetes sampathkumaranii*
22. *Isoetes tuberculata*
23. *Isoetes udupiensis*

Fig. 1: State-wise distribution of *Isoetes* species in India. Serial number of each species in above list is shown in the map of respective state

varieties viz., *I. indica* var. *harotiensis*, *I. pantii* var. *hybrida* and *I. panchananii* var. *pachmarhiensis* has been reported from Madhya Pradesh and are endemic to this region except *I. panchananii* that is reported from Maharashtra.

Species like *Isoetes sahyadrii*, *I. dixitii* and *I. panchganiensis* are described from Table-Land Plateau Panchgani (Maharashtra). These species have been collected from different regions of Maharashtra (Mahabaleshwar, Kas plateau and

Panhala) and Karnataka (Bababuddhangiri hills and Kemangundi hills). Recently, *Isoetes divyadarshanii* is described from Maharashtra by Shukla *et al.* (34). The species *I. sampathkumaranii*, *I. udupiensis* and a variety *I. panchganiensis* var. *kemangundiensis* are endemic to Karnataka.

A single subspecies of *Isoetes coromandeliana* subsp. *thanensis* has been reported from Than, Gujarat state (2).

Madhya Pradesh shelters seven species and three varieties of *Isoetes*, hence it appears to be most suitable habitat for *Isoetes*. Followed by Karnataka, which has 5 species and 1 variety, Maharashtra possesses 5 species and Rajasthan that has 4 species. In contrast, only one species is reported from North East India *i.e.* from Manipur. Mount Abu, Panchmari, Panchgani and Bababuddhangiri are the ideal hills that favor growth, development and speciation of the quillworts in India. The state wise distribution of each species is given in Fig. 1.

Phytogeography distribution of *Isoetes* in India

Phytogeographically, India is situated at the tri-junction of three realms-Afro-tropical, Indo-Malayan and Paleo-Arctic realms. India is one of the 12 mega biodiversity countries of the world and has a very rich and diverse heritage of biodiversity, including a wide range of habitats from tropical rainforests to alpine vegetation and from temperate forests to coastal wetlands including typical desert like great Rann of Kutchh. It provides shelter for many rare, threatened and endemic species that have massive ecological and commercial value. This assemblage of three different realms makes the country rich and unique in biological diversity. The subcontinent is bounded by efficient barriers like the Indian Ocean, the Himalayan ranges, the Western Ghats and the deserts of Sindh.

Whole country is divided into 10 biogeographic regions, including the Trans-Himalayan, the Himalayan, the Indian desert, the semi-arid zone(s), the Western Ghats, the Deccan Peninsula, the Gangetic Plain, North-East India, and the islands and coasts (36). The phytogeographic distribution of 12 species of *Isoetes* is studied by Shukla *et al.* (33), whereas remaining 11 species of *Isoetes* is given here in Fig. 2.

No records on *Isoetes* species are found from the Trans-Himalayan, the Himalayan region and The India desert. The maximum species were reported from the Deccan Peninsula (8 species *viz.*, *Isoetes bilaspurensis*, *I. coromandeliana*, *I. indica*, *I. fuchsii*, *I. mahadevensis*, *I. panchananii*, *I. pantii*, *I. sampathkumaranii* and 3 varieties *viz.*, *I. indica* var. *harotiensis*, *I. pantii* var. *hybrida* and *I. panchananii* var. *pachmarhiensis*), Western Ghats of India harbors 8 species (*viz.*, *I. coromandeliana*, *I. dixitii*, *I. divyadarshanii*, *I. indica*, *I. panchganiensis*, *I. sahyadrii*, *I. sampathkumaranii*, *I. udupiensis* and one variety *I. panchganiensis* var. *kemangundiensis*) and

the Semi-arid zone possess 5 species and 1 sub-species (*viz.*, *Isoetes coromandeliana*, *I. indica*, *I. rajasthanensis*, *I. reticulata*, *Isoetes tuberculata* and *I. coromandeliana* subsp. *thanensis*) whereas remaining phytogeographic zones having one, two or maximum three species. Among all these species *I. coromandeliana* is common and found in all phytogeographic regions.

Morphology and Palynology

Main characters like rhizomorph lobes, plant length, number of sporophylls, ligules, velum and megaspore ornamentation are used in the delimitation of different species of *Isoetes*.

Rhizomorph or *corm* is the underground, reduced stem and are bi-lobed or tri-lobed, rarely tetra-lobed or penta-lobed. This character is usually constant and reliable hence used to identify the species (3). Based on the lobe of rhizomorph all species of Indian *Isoetes* are grouped into two main categories *i.e.* bi-lobed and tri-lobed.

Bi-lobed category includes the species like *Isoetes mahadevensis*, *I. panchananii*, *I. panchananii* var. *pachmarhiensis*, *I. reticulata*, *I. rajasthanensis* and *I. sampathkumaranii*.

Tri-lobed category includes *Isoetes bilaspurensis*, *I. coromandeliana*, *I. coromandeliana* subsp. *thanensis*, *I. debii*, *I. divyadarshanii*, *I. dixitii*, *I. indica*, *I. indica* var. *harotiensis*, *I. pantii*, *I. panchganiensis*, *I. panchganiensis* var. *kemangundiensis*, *I. sahyadrii*, *I. tuberculata* and *I. udupiensis*.

Plant length and *number of sporophylls* are concerned with an expression of different degrees of ploidy levels and genomic constitution of the plants. Every species is having minimum and maximum number of sporophylls and length of sporophylls. On the basis of plant length and number of sporophylls different species can be identified. However, it may be influenced by soil type and climatic factors hence may be questionable and not much reliable one.

On the basis of plant length all Indian *Isoetes* are grouped into three categories *i.e.* small sized plant (height <20cm), medium sized plants (height >20 <40) and large sized plants (height >40 cm). *Small sized* species are *I. mahadevensis*, *I. panchganiensis*, *I. panchganiensis* var. *kemangundiensis*, *I. reticulata*, *I. rajasthanensis*, *I. sahyadrii* and *I. sampathkumaranii*. *Medium sized* species of *Isoetes* includes *I. bilaspurensis*, *I. dixitii*, *I. debii*, *I. panchananii*, *I. panchananii* var. *pachmarhiensis* and *I. pantii*. *Large sized* species are *I. coromandeliana*, *I. coromandeliana* subsp. *thanensis*, *I. divyadarshanii*, *I. indica*, *I. indica* var. *harotiensis*, *I. tuberculata* and *I. udupiensis*.

Ligule is present above the sporangia and lying parallel to the leaf surface. It is a thin, delicate, membranaceous, extension of tissue. Generally, it is triangular or deltoid in shape while in some species it shows curvature arms. On the basis of different

Phytogeographic distribution of genus *Isoetes* from India

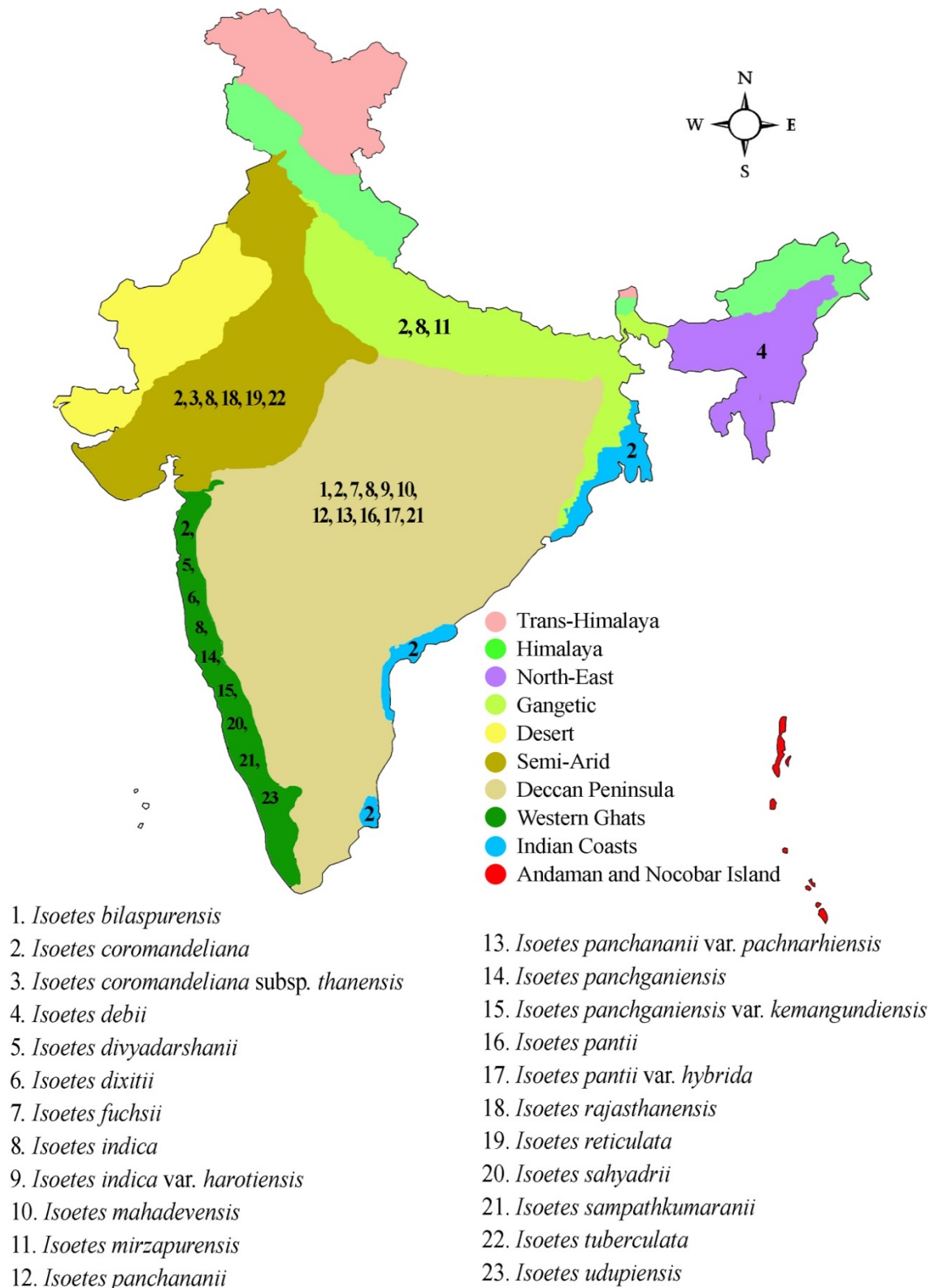


Fig. 2: Phytogeographic distribution of *Isoetes* in India

shapes of ligule, Sharma and Singh (37) identified different species.

Velum is the thin, membranaceous covering, present of sporangia (megasporangia or microsporangia). It is one of the important characters used for identification of different species

of *Isoetes* (Fig. 3). If velum is present, it completely covers the sporangia (e.g. *I. panchganiensis*), covers up to 1/3 or half of sporangia (e.g. *I. sahyadrii* and *I. sampathkumaranii*) or it is rudimentary as in case of *I. dixitii*. However, velum shows variability within the same population of a species; thus, it has limited

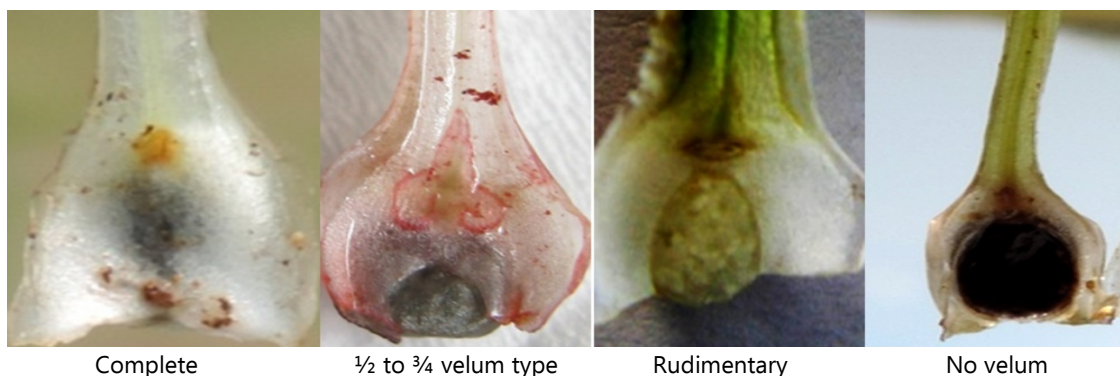


Fig. 3: Differences in velum characters in the genus *Isoetes* L.

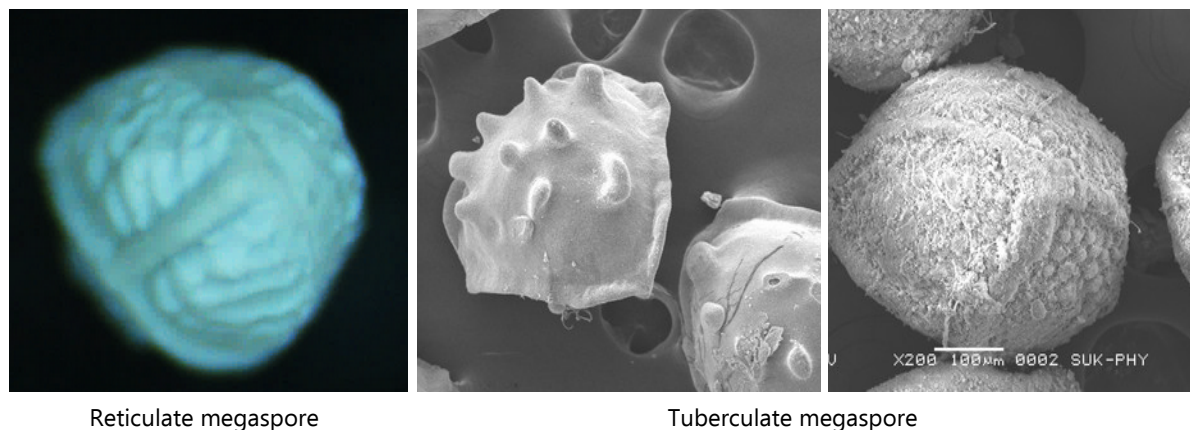


Fig. 4: Different types of megaspores in the genus *Isoetes* L.

taxonomic value (38). If the observations are based on the examination of a large number of populations and taken into its variability, its taxonomic importance remains unquestionable (3). On the basis of velum characters all India *Isoetes* species are grouped into four groups i.e. Plants with no velum, plants with rudimentary velum and velum may be complete or 1/2 to 3/4 in length of sporangium.

No velum group includes nine species: *I. coromandeliana*, *I. coromandeliana* subsp. *thanensis*, *I. debii*, *I. divyadarshanii*, *I. indica*, *I. indica* var. *harotiensis*, *I. pantii*, *I. tuberculata* and *I. udupiensis*. *Rudimentary velum group* includes only two species *I. dixitii* and *I. mahadevensis*. *Group with 1/2 to 3/4 in length* includes *I. bilaspurensis*, *I. panchananii*, *I. panchananii* var. *pachmarhiensis*, *I. reticulata*, *I. rajasthanensis*, *I. sahyadrii* and *I. sampathkumaranii* while complete velum is observed in *I. panchganiensis*, *I. panchganiensis* var. *kemangundiensis*.

Spores are the reproductive unit, having ability to produce new individuals. In different genera, they are either monosporic (having only one type of spores, e.g. *Lycopodium* L. & *Huperzia* Bernh.) or heterosporic (having two different types of spores, e.g. *Isoetes* L. & *Selaginella* P. Beauv.). The genus *Isoetes* is a heterosporous lycophyte having two types of spores i.e. microspore (small sized) and megaspore (large sized spore). Megaspore ornamentation is one of the important characters used to identify the species of *Isoetes*. On the basis of megaspore ornamentation, Pfeiffer (13) and Fuchs

(39) grouped different species *Isoetes* into 5 sections: They are as follows,

- Tuberculatae: Megaspores tuberculate
- Echinatae: Megaspores spiny
- Cristatae: Megaspores irregularly crested
- Reticulatae: Megaspores reticulate, at least on basal face
- Lavigate: Megaspores having fine powder

Majority of *Isoetes* species from India were described on the basis of megaspore ornamentation. All Indian species are belonging to section tuberculatae and reticulate (Table 1, 2 and 3; Fig. 4) whereas no Indian taxa which could be assigned to the sections echinatae, cristatae and lavigate. In the section tuberculatae exine of megaspores having tubercles, they are either round apices or pointed apices (e.g. *I. indica*) whereas in reticulate section exine of megaspores having reticulated striations.

After a critical review of literature and observation of morphological as well as palynological characters, it was observed that "the species that are having velum possess reticulate spores except (*Isoetes dixitii* and *I. sahyadrii*) while species lacking velum show presence of tuberculate megaspore. On these observations, it may be concluded that *I. dixitii* and *I. sahyadrii* are the intermediate forms of tuberculate and reticulate spore groups.

Table 1: Two-state characters used for Numerical Taxonomy

Characters taken	Character state	
	(0)	(1)
Amphibious	Non amphibious	Amphibious
Submerged	Non Submerged	Submerged
Terrestrial	Non terrestrial	Terrestrial
Plant size < 20 cm,	No	Yes
Plant size > 20 cm but <40 cm	No	Yes
Plant size > 20 cm but <40 cm	No	Yes
Rhizomorph bi-lobe	No	Yes
Rhizomorph tri-lobe	No	Yes
Ligule	Cordate	Deltoid
Peripheral strands	Absent	Present
Velum	Absent	Present
Rudimentary	No	Yes
Half of the sporangia	No	Yes
3/4 or complete	No	Yes
Megaspores nature monomorphic	No	Yes
Megaspores nature dimorphic	No	Yes
Megaspores nature trimorphic	No	Yes
Megaspore ornamentation tuberculate	Non tuberculate	Tuberculate
Megaspore ornamentation reticulate	Non reticulate	Reticulate
Microspore ornamentation	Echinate	tuberculate

Similarly, species having reticulate megaspores possess bi-lobed rhizomorph while species having tuberculate megaspores show presence of tri-lobed rhizomorph.

Anatomy

Anatomy has always found to play an important role as a supplementary discipline in identification or delimitation of taxa. However, in pteridophytes anatomical characters are rarely used for the identification. Anatomically *Isoetes* is characterized by presence of peripheral strands, stomata and air chambers. Amongst these, presence of peripheral strands is an important one while character like stomata and air chamber are used as supporting characters. *Peripheral strand* is an anatomical feature, which associated with “conductive tissue” present at the corners of leaves” and additionally it also provides mechanical strength to sporophylls in order to keep them stand erect. Taxonomically it is important feature that is used for the identification of closely related species (2,3,20,23,29,34,40).

The peripheral strands are present in the species viz., *I. oromandeliana*, *I. coromandeliana* subsp. *thanensis*, *I. divyadarshanii*, *I. dixitii*, *I. indica*, *I. pantii*, *I. tuberculata* and *I. udupiensis* whereas they are absent in *Isoetes mahadevensis*, *I. panchganiensis*, *I. panchganiensis* var. *kemangundiensis*, *I. panchananii*, *I. panchananii* var. *pachmarhiensis*, *I. reticulata*, *I. sahyadrii* and *I. sampatkumarnii*. However, its presence or absence is unknown due to lack of studies on species viz., *I. bilaspurensis*, *I. debii*, *I. fuchsii*, *I. indica* var. *harotiensis*, *I. mirzapurensis*, *I. pantii* var. *hybrida* and *I. rajasthanensis* (2,3,20,23,29,34,40). It is interesting to note that all those species lacking peripheral strands are having reticulate spores while those species having peripheral strands show presence of tuberculate spores (except *I. sahyadrii*). Therefore, above mentioned observation also support our previous statement that *I. sahyadrii* is the intermediate forms of tuberculate and reticulate spore groups.

Phenology

In species like *I. coromandeliana*, *I. coromandeliana* subsp., *thanensis*, *I. dixitii*,

Bray-Curtis Cluster Analysis (Single Link)

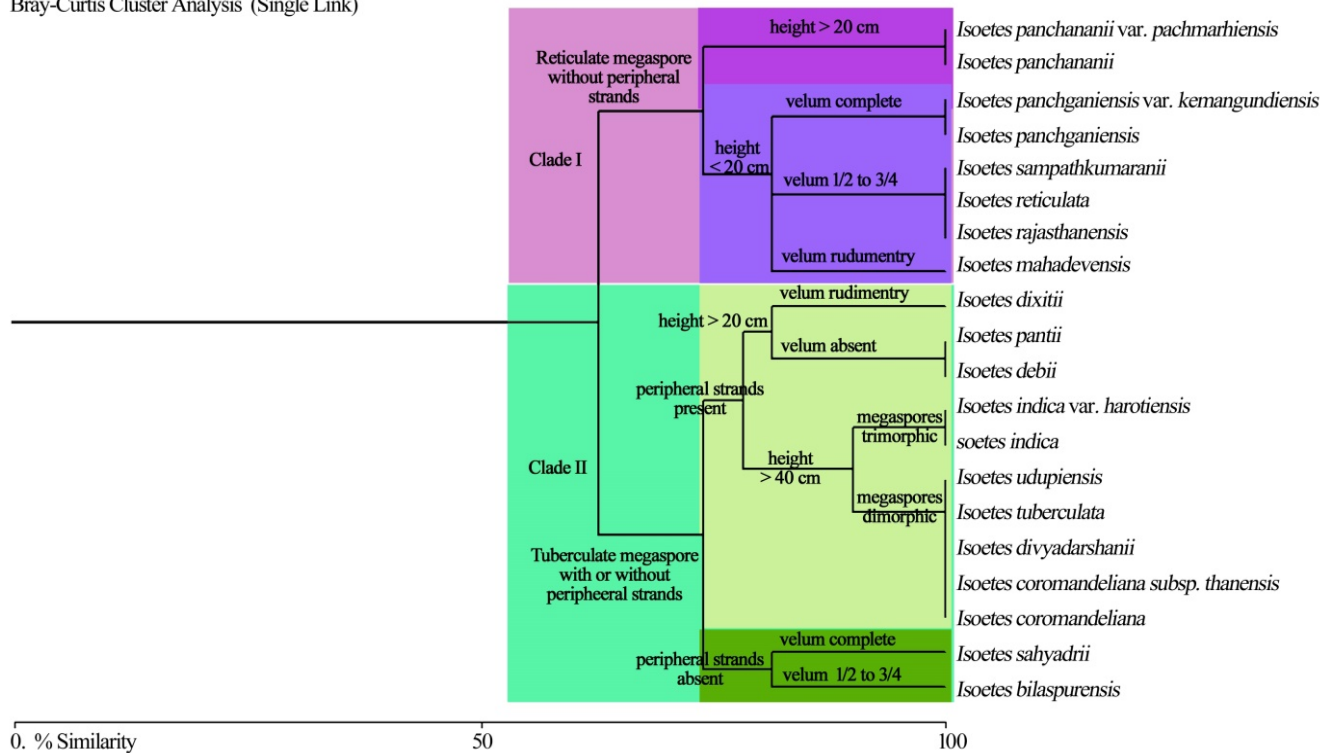


Fig. 5: cluster analysis of the genus *Isoetes* L. from India

I. divyadarshanii, *I. indica*, *I. sahyadrii* and *I. udupiensis* spore germination starts after first shower of rains i.e. during June-July, become mature and produces spores during the month of August-September and undergoes dormant condition after October-November. However, in *Isoetes panchganiensis* germination starts at the end of rainy season i.e. in the month of September, saplings developed from spores become mature and produces sporangia in the month of November-December and undergoes dormant condition after January (2,34,40). Similar information is warranted on the remaining species and they are yet to be studied for the phenological events occurring in their life cycle.

Cytology

Cytological studies on *Isoetes* were initiated by Ekambaram and Venkatanathan (41) and described the process of sporogenesis in *I. coromandeliana* and reported that formation of two sterile and two fertile spores from a tetrad. Abraham and Ninan (42) studied cytology of *I. coromandeliana* and documented $2n = 22$ (Table 1) while cytological and phylogenetic studies of family Isoetaceae were carried out by Ninan (43). Verma (44) studied the cytology of *I. coromandeliana* explored the account of enucleate and nucleate spores. Subsequently, several cytological studies were also carried out by earlier researchers (45, 46,47,48,49,50). Tripathi and Yadav (51) also described the cytology of *Isoetes* from Rajasthan and reported diploid, tetraploid and pentaploid conditions.

Cytological study conducted by Goswami and Bhu (52) led to the conclusion that *I. pantii* is a natural hybrid of *I. sampathkumaranii* and *I. coromandeliana*. Recently, Shukla *et al.* (2,34) described two new species and one subspecies on the basis of chromosome number. Nevertheless, several species of *Isoetes* remains to be explored for their cytology and further studies are warranted on this line (Table 2, 3 & 5).

Numerical Taxonomy

The morphometric study was also performed to delineate the taxa of *Isoetes* at the species and infra-species level. For numerical taxonomic study the 20- state characters are used the species as well as infra-species level with coded in a data matrix as '1' and '0' respectively (Table 1). They are viz., habitat characters (amphibious or submerged or terrestrial), plant size (< 20 cm, > 20 cm but <40 cm and > 40 cm), rhizomorph lobbing (bilobed or trilobed), ligule (cordate or deltoid), peripheral strands (present or absent), velum (present or absent), velum coverage (rudimentary, half, 3/4 or complete), microspore ornamentation (reticulate or tuberculate), megaspores nature (dimorphic, monomorphic or trimorphic) and megaspore ornamentation (reticulate or tuberculate). The dendrogram was generated by Bary-Curtis cluster analysis. In this dendrogram all the *Isoetes* L.f. species are fall under two major clades i.e. tuberculate megaspores with or without peripheral strands and reticulate spores without peripheral strands (Fig. 5).

Table 2: Important characteristics of Indian *Isoetes* species along with their distribution and sporophytic count

Attributes/Name of Species	<i>I. bilaspurensis</i>	<i>I. coromandeliana</i>	<i>I. coromandeliana</i> subsp. <i>thanensis</i>	<i>I. debii</i>	<i>I. divyadarshanii</i>	<i>I. dixitii</i>
Authors	G. Panigrahi, 1981	Linnaeus filius, 1781	K. Shukla, S.K. Singh, P.K. Shukla, N.K. Dubey, H. Khanam & G.K. Srivastava, 2017	S. C. Sinha, 1992	P. K. Shukla, G. K. Srivast. & S. K. Shukla, 2006	D. V. Shende, 1945
Type Locality	Bilaspur, Madhya Pradesh	Coromandel coast, Tamil Nadu	Than, Gujarat	Nambol, Manipur	Lonavala, Maharashtra	Panchgani, Maharashtra
Plant size	Less than 40 cm	More than 40 cm	More than 40 cm	Less than 40 cm	More than 40 cm	Less than 40 cm
Rhizomorph	Tri-lobed	Tri-lobed (rarely tetra or penta lobed)	Tri-lobed	Tri-lobed	Tri-lobed	Tri-lobed
Sporophylls per plant	15-30	17-59 (in triploid) 8-23 (in tetraploid)	Up to 86	30-75	Up to 85	6-32
Peripheral strands	Unknown	4-main, several subsidiary strands	5-10 minor	Unknown	3-5 not strongly developed	4-main, 20-30 subsidiary strands
Velum	2/3 to 3/4 covering the sporangia	Absent	Absent	Absent	Absent	Rudimentary (very small)
Ligule	Triangular	Triangular-cordate	Triangular	Triangular-deltoid	Triangular-cordate	Triangular-deltoid
Megaspores	Tuberculate	Tuberculate, tubercles even	Dimorphic, tuberculate	Tuberculate	Monomorphic, tuberculate	Dimorphic, Tuberculate, tubercles uneven
Distribution	Madhya Pradesh	Throughout India	Gujarat	Manipur	Maharashtra	Maharashtra
Chromosomes	Unknown	2n=22+1; 2n=33+1 2n=44+1	2n=22+1	Unknown	2n=22	2n=44+1 (Unpublished)
References	Panigrahi, 1981; Srivastava <i>et al.</i> , 1992; Srivastava, 1998	Pant and Srivastava, 1962; Srivastava <i>et al.</i> , 1992; Srivastava, 1998	Shukla <i>et al.</i> , 2017	Sinha, 1992; Srivastava, 1998	Shukla <i>et al.</i> , 2005; Patil <i>et al.</i> , 2013	Shende, 1945; Srivastava <i>et al.</i> , 1992; Srivastava, 1998; Patil <i>et al.</i> , 2013

Table 3: Important characteristics of Indian *Isoetes* species along with their distribution and sporophytic count

Attributes/Name of Species	<i>I. indica</i>	<i>I. indica</i> var. <i>harotiensis</i>	<i>I. mahadevensis</i>	<i>I. panchananii</i>	<i>I. panchananii</i> var. <i>pachmarhiensis</i>	<i>I. pantii</i>
Authors	D. D. Pant & Srivastava, 1962	Bhardwaj & Gena, 1992	G. K. Srivastava, D. D. Pant & P. K. Shukla, 1993	D. D. Pant & G. K. Srivastava, 1962	G. K. Srivastava, M. Srivastava, P. K. Shukla, 1977	H. K. Goswami & B. S. Arya, 1970
Type Locality	Ram Nai Rewa, Madhya Pradesh	Rajasthan	Pachmarhi, Madhya Pradesh	Ram Nai Rewa, Madhya Pradesh	Jata Shankar, Pachmarhi	Narsingharh, Madhya Pradesh
Plant size	Up to 56 cm	Up to more than 40 cm	5-15 cm	Up to 25 cm	8-34 cm	15-33 cm
Rhizomorph	Tri-lobed (rarely tetra-lobed)	Tri-lobed	Bi-lobed (rarely tri-lobed)	Bi-lobed	Bi-lobed	Tri-lobed
Sporophylls per plant	09-35	Unknown	5-29	4-38	11-35	15-39
Peripheral strands	Main 4-6 with many subsidiary strands	Unknown	Absent	Absent	Absent	Present
Velum	Absent	Absent	Rudimentary	Half (rarely complete)	1/2 to 3/4	Absent
Ligule	Triangular	Triangular	Triangular	Triangular	Triangular	Unknown
Megaspores	Tuberculate, tubercles	Tuberculate, tubercles	Reticulate	Reticulate	Cristate reticulate	Tuberculate
Chromosomes	2n=44+1	2n=44	2n=44+1	2n=44+1; 2n=55+1	2n=44+1	2n=22+2; 2n=33 +1, 2 or 3; 2n=44 (+1 or 2)
Distribution	Madhya Pradesh, Karnataka, Gujarat, Tamil Nadu	Madhya Pradesh	Madhya Pradesh	Madhya Pradesh	Madhya Pradesh	Madhya Pradesh
References	Pant and Srivastava, 1962; Srivastava, 1998	Bhardwaj & Gena, 1992; Srivastava, 1998	Srivastava <i>et al.</i> , 1993; Srivastava, 1998	Pant and Srivastava, 1962; Vasudeva & Bir, 1982	Srivastava <i>et al.</i> , 1993; Srivastava, 1998;	Goswami & Arya, 1970; Goswami, 1975

Table 4: Important characteristics of Indian *Isoetes* species along with their distribution and sporophytic count

Attributes/Name of Species	<i>I. panchganiensis</i>	<i>I. panchganiensis</i> var. <i>kemangundiensis</i>	<i>I. rajasthanensis</i>	<i>I. reticulata</i>	<i>I. sahyadrii</i>	<i>I. sampathkumaranii</i>
Authors	G. K. Srivastava, D. D. Pant & P. K. Shukla, 1993	G. K. Srivastava, D. D. Pant & P. K. Shukla, 1993	C. B. Gena & T. N. Bhardwaj, 1984	C. B. Gena & T. N. Bhardwaj, 1984	T. S. Mahable, 1938	L. N. Rao, 1944
Type Locality	Panchgani, Maharashtra	Kemangundi, Karnataka	Kota, Rajasthan	Mount Abu Rajasthan	Panchgani Maharashtra	Bangalore, Karnataka
Plant size	9-15 cm	Up to 15 cm	7.5-12 cm	4-10 cm	Up to 20 cm	11 cm
Rhizomorph	Tri-lobed	Tri-lobed (rarely tetra-lobed)	Bi-lobed	Bi-lobed	Tri-lobed	Bi-lobed
Sporophylls per plant	9-20	09-35	Unknown	6-24	4-32	3-16
Peripheral strands	Absent	Absent	Unknown	Absent	Absent	Absent
Velum	Complete	Absent	Absent	Covered entire sporangium, except a base arched slit	Covered entire sporangium, except a base arched slit	1/2 to 3/4
Ligule	Triangular	Triangular	Triangular	Triangular	Triangular with armed	Triangular
Megaspores	Reticulate	Reticulate	Reticulate	Reticulate	Tuberculate	Reticulate
Chromosomes	2n=33+1 (Unpublished)	2n=44+1	2n=44	2n=55	Unknown	2n=66
Distribution	Maharashtra	Karnataka	Rajasthan	Rajasthan	Maharashtra	Karnataka
References	Srivastava <i>et al.</i> , 1993; Srivastava, 1998; Patil, 2014	Srivastava <i>et al.</i> , 1993; Srivastava, 1998	Gena & Bhardwaj, 1984; Bhardwaj & Gena, 1992; Srivastava, 1998;	Gena & Bhardwaj, 1984; Bhardwaj & Gena, 1992; Srivastava, 1998	Mahable, 1938; Srivastava, 1998;	Rao, 1944; Abraham & Ninan, 1958; Ninan, 1958; Srivastava, 1998;

Table 5: Important characteristics of Indian *Isoetes* species along with their distribution and sporophytic count

Attributes/Name of Species	<i>I. tuberculata</i>	<i>I. udupiensis</i>	<i>I. fuschii</i>	<i>I. pantii</i> var. <i>hybrida</i>	<i>I. mirzapurensis</i>
Authors	C. B. Gena & T. N. Bhardwaj, 1984	P. K. Shukla, G.K. Srivastava, S.K. Shukla & P.K. Rajagopal, 2005	I. Bhu, H. K. Goswami, U. S. Sharma & A. K. Bajpai, 2001	H. K. Goswami, 2004	Panigrahi & R. D. Dixit, 1966
Type Locality	Artu (Kota) Rajasthan	Udupi, Karnataka	-	-	-
Plant size	30-45 cm	29-41	-	-	-
Rhizomorph	Tri-lobed (rarely bilobed)	Tri-lobed	-	-	-
Sporophylls per plant	9-33	Up to 67	-	-	-
Peripheral strands	Not mentioned	Present	-	-	-
Velum	Absent	Absent	-	-	-
Ligule	Triangular	Cordate	-	-	-
Megaspores	Tuberculate	Tuberculate	-	-	-
Chromosomes	2n=44	2n=22	-	-	-
Distribution	Rajasthan		Madhya Pradesh	Madhya Pradesh	Utter Pradesh
References	Gena & Bhardwaj, 1984 Srivastava <i>et al.</i> , 1993; Srivastava, 1998;	Srivastava <i>et al.</i> , 1993; Srivastava, 1998	Bhu <i>et al.</i> , 2001	H. K. Goswami, 2004	Panigrahi & Dixit, 1966; Panigrahi, 1981

Present Taxonomic Scenario

Chandra *et al.* (53) studied status of threatened pteridophytes of India and commented on the doubtful taxonomic status of the Indian species. Fraser-Jenkins (54) considered the existence of at least two species of *Isoetes* in India, from which *I. coromandeliana* is a common one, while name of the second species remains undecided. Fraser-Jenkins (54) did the lectotypification and epitypification of *I. sahyadriensis* and decided a second species of *Isoetes* from India. In recent study, Fraser-Jenkins (5) accepted four species of *Isoetes* (viz., *I. coromandeliana*, *I. dixitii*, *I. sahyadrii* (i.e. *I. sahyadriensis*) and *I. udupiensis* from India in his publication "An Annotated Checklist of Indian Pteridophytes Part – 1. He also mentioned about 25 species (19 species, 4 varieties and one subspecies) have been described by earlier researchers cataloguing variation in their micromorphology of megaspore, its types, their ornamentation, peripheral strands, velum, ligules, presence of different spores and fused spores in the sporangium. However, his critical observations on the above mentioned features led him to conclude occurrence of only four species in India. His conclusion appears to be based on study carried out on dry specimens from various herbaria and dry specimen may lose some fine details (like ligule, velum, etc.) during drying and these structures are important in delimitation of taxa. However, *Isoetes* is delicate fern with poorly developed vasculature; therefore, thorough revision is required to resolve the issue related with number of species in India.

Conclusion

After reviewing the genus *Isoetes* from India, it is observed that all 23 species are grouped into two groups i.e. reticulate and tuberculate on the basis of their spore morphology. Further it is also observed that reticulate species having bi-lobed rhizomorph, sporangia covered with velum and lacking peripheral strands. In contrast, tuberculate species show tri-lobed rhizomorph, sporangia without velum and show presence of peripheral strands (except *Isoetes dixitii*, *I. sahyadrii* and *I. bilaspurensis*). Another thing is that, due to high endemism and lack of data on cytology, is not quantifiable the taxonomic problems with reference to delimitation of species and excess naming of spore-variants as species. Moreover, morphology of certain species like *Isoetes fuchsii*, *I. pantii* var. *hybrida* and *I. mirzapurensis* is not known. Therefore, present study emphasizes the necessity of the inventorization by continuous searching and re-examination of different species of *Isoetes* distributed in India. Present study also suggest need of further studies to explore the taxonomy of the Indian *Isoetes*, coupled with the data on their ecology, phenology, spore morphology, cytology and molecular studies.

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Conflict of Interest

The authors have no conflict of interest.

Authors' Contribution

SMP collected some of the specimens, and compiled the data from the literature. KSR helped in writing the results and over all compilation of the manuscript

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