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REVIEW ARTICLE

A review of the current state of knowledge on *Pseudoxytenanthera ritchiei*- a lesser-known bamboo species with high utilization potential from Peninsular India

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Abstract: *Pseudoxytenanthera ritchiei* (Munro) H. B. Naithani is a unique bamboo species with fully solid culms. This bamboo species is endemic to the Peninsular India and has a scattered distribution in the forest ecosystems of Kerala. In Kerala, the species was abundantly found in Nilambur and Mannarkad forests and had high demand in the market. However, unsustainable harvesting over a significant period resulted in resource depletion from these forests (Kumar *et al.,* 2009). Though *P. ritchiei* shares many characteristics which make *Pseudoxytenanthera stocksii* a commercially important bamboo species, the former is not listed as a priority species by the National Bamboo Mission while the latter is included in the list. Moreover, the potential of *P. ritchiei* remains untapped in Kerala, primarily due to a lack of information on its distribution and availability, and secondly due to a lack of supply of sufficient quantity for commercial use. These are clumping bamboo and do not require much space, making them suitable for home gardens and as a border crop in fields. Hence, we argue that there is a good justification for this species to be given preference and large-scale cultivation to be encouraged outside forest areas after having developed appropriate methods for quality stock production. Steps must also be taken to ensure the conservation of the species in its natural habitat to prevent the loss of the wild and diverse genotypes which at present lack sufficient documentation. This review features information gleaned from available literature on this less-studied species, and its potential for utilization. The currently available information relating to distribution, propagation, floral morphology, flowering history, eco-system services etc. is also highlighted.

Keywords:Pseudoxytenanthera ritchiei, Pseudo-xytenanthera stocksii, distribution, carbon sequestration, ecosystem services

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Introduction

Pseudoxytenanthera ritchiei (Munro) H.B. Naithani is a thornless, medium-sized, strong, and entirely solid bamboo species that is endemic to the Peninsular India. It has a dispersed distribution in states such as Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, and Maharashtra in Indian Union, as a component of moist deciduous forests (BSI ENVIS; Kumar, 2011; Kellog *et al*., 2020). It is a sympodial, light-demanding species that grows within an elevation range from 200 to 1100 m MSL. The species is sturdy and is as strong as cane, making it a suitable substitute in cane industry (Krishnankutty and Mammen, 2009). This species is found to survive on rocky and shallow soils, and is usually found to grow on extreme sites such as the top of hills, ridges, and slopes (Bhanadri, 1981; Sankar and Muralidharan, 2017).

P. ritchiei is known by various local names, such as *'Erankol'* in Nilambur and '*Korna'* in the Mannarkad region, both in Kerala. It is referred to as 'Udha', 'Udhe', 'Huda', 'Manga' and 'Tandali' in Pune, while 'Chiwa', 'Chiwan', and 'Chawa' are its names in the Satara Ghat regions, both in Maharashtra (Kulkarni *et al*., 2001). The species has a wide range of localized uses among the forest-dependent community from as a source of nutrition to utilization as a structural material in construction. Apparently, there is a significant reduction in the natural population of this species owing to the large-scale unsustainable and unscientific extraction from the forests for various end uses (Kumar *et al*., 2009). Conversion of forest land for agricultural purposes and the establishment of large-scale plantations such as rubber and teak also contributed to large-scale resource depletion (Krishnankutty and Mammen, 2009). According to Jijeesh *et al*., 2020 the species is conservation dependent as per the IUCN standards, so proper conservation strategies for the sustainable use of this resource must be developed. This review aims to provide a concise overview of the information on the species available from published sources, particularly the information pertaining to nomenclatural history, distribution range, habit, floral morphology, flowering history, propagation methods, ecosystem services, threats to the survival of the species in its natural habitat, policy and trade, cultivation potential, and future research and development requirements of *P. ritchiei*, in order to serve as a reference material for further development of research in the field.

Nomenclatural history

The species was given the binomial name *Bambusa ritcheyi* Munro by Munro in 1868. The name was based on an herbarium specimen that was collected by Dr. David Ritchie in 1852 from a rivulet located near the fall on the Kala Nuddi in Bombay (NHM, Vienna). In the addenda to the same publication, the author reconsidered the spelling of the ritcheyi to 'ritchiei' to honour the collector, nevertheless, many authors continued to use earlier spelling without considering the revision in the species name (Munro, 1868, 1983). When Beddome discovered monostigmatic ovary in the species in 1873, the name was revised as *Oxytenanthera monostigma* Bedd. (Beddome, 1873). Gamble, while revising the Indian Bambusaceae in the year 1896, confirmed that the two species were identical, yet he chose to use the name *Oxytenanthera monostigma* Bedd. over Munro's nomenclature despite him being uncertain about the revision in the name (Gamble, 1896). Later, authors of various regional flora including Brandis (1906), Bourdillon (1908), Talbot (1911) and Camus (1913) followed Gamble without resolving the nomenclatural ambiguity.

In 1929, Blatter and Mc Cann noticed the confusion and changed the name *Oxytenanthera monostigma* to *Oxytenanthera ritcheyi* (Munro) Blatt. & Mc Cann, but the spelling chosen by the authors was the one earlier discarded by Munro (Blatter and Mc Cann, 1929). In the year 1982, Nair and Ansari proposed the same combination as *Oxytenanthera ritcheyi* (Munro), by using the specific epithet of *Bambusa ritcheyi* Munro and the name was changed to *Oxytenanthera ritcheyi* (Munro) V.J. Nair & R. Ansari (Nair and Ansari, 1982). However, in 1989, Majumdar demonstrated that the Indian species of *Oxytenanthera* differed from the type genus of *Oxytenanthera* as it possesses subscandent to scandent branches in tufts, thin solid style, thinner pericarp which is separable from seed and has no resting central bud. Hence proposed a new genus *Pseudotenanthera* and the species name was changed to *Pseudotenanthera ritchiei* (Munro) R.B. Majumdar (Majumdar, 1989). However, Naithani (1990) noted that the characteristics of the genus *Pseudotenanthera* are similar to the genus *Pseudoxytenanthera* as described by Soderstrom and Ellis. As a result, *Pseudotenanthera* was considered a superfluous name and treated as a synonym of *Pseudoxytenanthera* and a novel combination, *Pseudoxytenanthera ritcheyi* (Munro) H.B. Naithani was proposed. Ohrnberger proposed the isonym *Pseudoxytenanthera ritchiei* in 1997, based on the corrected spelling (Ohrnberger, 1999). During revisionary studies of Indian bamboos, Kumar and Remesh (2008) noted the presence of completely solid culms, prophyllum buds and palea without keels, mono-stigmatic ovary, and united filaments, which differ from the genus *Pseudoxytenanthera*. Consequently, a new genus *Munrochloa* was proposed and the species was named *Munrochloa ritchiei* (Munro) M. Kumar & Remesh, with the generic name in honour of Colonel William Munro who originally described and named the species about 140 years back in 1868.

Although *Munrochloa ritchiei* (Munro) M. Kumar & Remesh is the most recent name, it is considered a synonym by plant taxonomic resources such as 'World Checklist of Selected Plant Families' (WCSP) and 'Plants of the World Online' (POWO), while the new name is accepted by 'The World Flora Online' (WFO)'. According to POWO, other names like *Schizostachyum hindostanicum* and *Arundarbor ritcheyi*, which were suggested by German botanists S. Kurz and Otto Kuntze, respectively, are also recognized as synonyms for this species (Kurz, 1873; Kuntze, 1981).

Despite a spelling error, the valid and currently accepted name by WCSP is *Pseudoxytenanthera ritcheyi* (Munro) H.B. Naithani, while POWO has accepted the name *Pseudoxytenanthera ritchiei* (Munro) H.B. Naithani. Hence, in this review, the name *Pseudoxytenanthera ritchiei* (Munro) H.B. Naithani is used.

A list of Synonyms of *Pseudoxytenanthera ritchiei* (Munro) H.B. Naithani and references to publications are provided in the Table 1.

Distribution

Pseudoxytenanthera ritchiei is mostly found in the moist deciduous forests of the Western Ghats in Peninsular India, especially in the states of Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, and Maharashtra (BSI ENVIS; Kumar, 2011; Kellog *et al*., 2020). In Tamil Nadu, *P. ritchiei* was reported from the forests of Anamalais and Coimbatore (Bourdillon, 1908; Blatter and McCann, 1935; Ohrnberger, 1999). The species is found in the forests of Kasaragod, Kannur, Kozhikkode, Malappuram, Palakkad, Pathanamthitta, and Kollam districts in Kerala. It is found in the forest divisions of Mannarkad and Nilambur in Kerala state. Populations can be found in Adankulam, Kornakkunnu, Karimala ridge, and in the hill slopes of Anamooli, Melamuri, Thathengalam, and Varakkallu in the Mannarkad forest division (Kumar *et al*., 2009). *P.ritchiei* can also be found in Manthapotty and Silent Valley in the Palakkad District, in addition to the Mannarkad forest division (Kumar and Remesh, 2008; Sasidharan *et al*., 1994). It grows in discrete patches in Ambumala, Erankolkunnu, Manikyamudi Pothukal, Edavanna ranges and Vazhikkadavu ranges in Nilambur forest division in Kerala (Beena *et al*., 2007; Kumar *et al*., 2009; Kuruvilla *et al*., 2016). *P. ritchiei* has been observed as an element in home gardens in these localities, where the original planting stock is mostly gathered from adjacent forests. In Kozhikode forest division of Kerala, the species is reported from Peedikappara section of Thamarassery forest range (Working Plan, Kozhikkode Forest Division, 2011-2021) and in Kasaragod district it is reported from Panathur and Panathady (Kumar, 2011). Though the working plans of Kannur Forest division and Ranni Forest Divisions report occurrence of *P. ritchiei,* exact locations of occurrences are not mentioned (Working Plan, Kannur Forest Division, 2013-2023; Working Plan, Ranni Forest Division, 2002-2012). *P. ritchiei* is reported from Kulathupuzha valley in Kulathupuzha forest range in Kollam District (Working Plan, Thiruvananthapuram Forest Division, 2004-2014).

Table1. *Pseudoxytenanthera ritchiei* (Munro) H.B. Naithani, list of Synonyms

Synonyms	Reference
Bambusa ritcheyi Munro	Munro,1868,1983
Bambusa ritchiei Munro	Munro,1868,1983
Oxytenanthera monostigma Beddome	Beddome, 1873
Schizostachyum hindostanicum Kurz	Kurz, 1873
Arundarbor ritcheyi Kuntze	Kuntze, 1891
Oxytenanthera ritcheyi (Munro) Blatter & McCann	Blatter and Mc Cann, 1929
Oxytenanthera ritcheyi (Munro) V.J. Nair & R. Ansari	Nair and Ansari, 1982
Pseudotenanthera ritchiei (Munro) R.B. Majumdar	Majumdar, 1989
Pseudoxytenanthera ritcheyi (Munro) H.B. Naithani	Naithani, 1990
Pseudoxytenanthera ritchiei (Munro) Ohrnberger	Ohrnberger, 1999
Munrochloa ritchiei (Munro) M. Kumar & Remesh	Kumar and Remesh, 2008

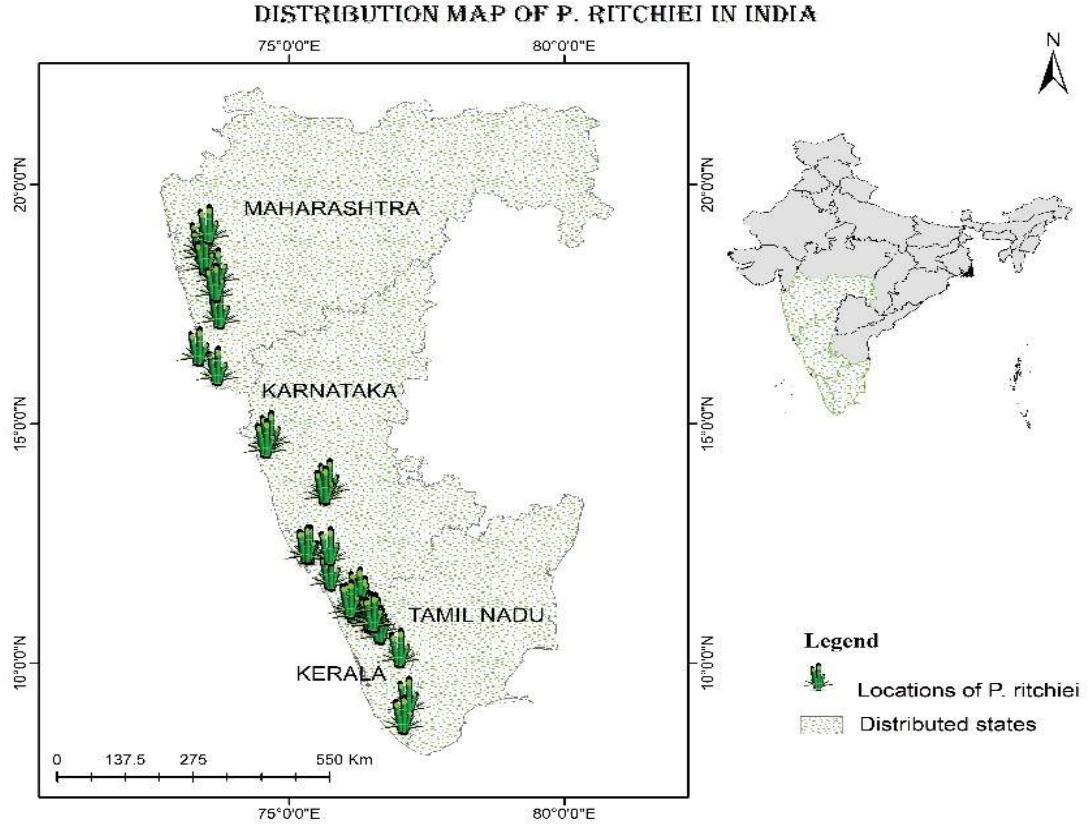

Fig 1. Distribution map of *P. ritchiei* in India

Kadambi had recorded *P. ritchiei* from the sugalatti hills of Bhadravathi forest division of Mysore state in the year 1937 (Kadambi, 1949). The species has been reported in Karnataka from the Lakkavalli, Muthodi, and Hebbe ranges of the Bhadra Wildlife Sanctuary (Vasanthakumari *et al*., 2010). Although information is available on the presence of the species in Andhra Pradesh, exact locations are not found in any published reports (Kellog *et al*., 2020). The species is also reported from Sindhudurg, Raigad, Ratnagiri, and Kohlapur districts of Maharashtra state in India (Waghmare and Bagde, 2012, 2013; Patil, 2018). Apart from documentation of the few locations in herbarium collections, floras, and monographs, no study of the complete distribution range of *P. ritchiei* in any state has been found. The distribution map of the species prepared from the available literature is shown in Fig 1.

Taxonomic description

Pseudoxytenanthera ritchiei is a medium-sized, strong straggling bamboo with loosely spaced culms that develops from long-necked pachymorph rhizomes (Fig. 2). A well-established clump usually has a circumference of about 11m and two adjacent culms are found to maintain a minimum distance of 22 cm. The culms are straight and solid, reaching a height up to 10 m. However, in undisturbed patches, it is found growing up to a height of 15 m (Fig. 2.A). Each culm contains 20-40 internodes with an internode length ranging between 20 and 40cm and a diameter from 2.5 to 4 cm. When young, the internodes are thickly covered with golden yellow tomentum and smooth when old. Nodes are prominent with a sheath scar and a nodal bud is enclosed within the prophyllum. Culm sheaths are deciduous, measuring 15–26 cm in length and 6–9 cm in width at the base. It has golden brown hairs when young and glabrous when mature. Culm sheath blades are erect, narrow, and attached to the culm sheath but fall with age. The auricle is absent. Branches emerge from the lower nodes, with a central primary branch developing first and becoming dominant, followed by 3-4 secondary branches. Branches are arranged opposite to one another, and they rebranch

Fig 2. Natural distribution of *P. ritchiei* in forest areas of Nilambur (A) and Mannarkad in Kerala state (B).

from their nodes to form a cluster. Pale green, linear-lanceolate leaves appear on branches and are 12-24 cm long and 1-3 cm wide, glabrous on both sides and scabrous along one of the margins. The leaf base shortly attenuates to a very short petiole (Seethalakshmi *et al.*, 1998).

P. ritchiei and *P. stocksii*- A comparison

Pseudoxytenanthera ritchiei is very similar to *Pseudoxytenanthera stocksii* a commercially important bamboo species which is morphologically similar in many characters such as habitat, leaf size, solidness. Both species are thornless and easy to manage. The similarities and differences between the two species are listed in Tables 2 and 3. The National Bamboo Mission (NBM) has prioritized promotion of 18 species of bamboos based on their industrial and economic value, including *P. stocksii* which is currently in high demand in the agricultural sector as well as the construction and furniture industries (Rane *et al*., 2016). Molecular studies on these species revealed common RAPD bands, indicating close genetic affiliation among the *P. ritchiei* and *P. stocksii* (Waghmare and Bagde, 2013). The culms of species have been used for various purposes ranging from walking sticks, umbrella handles, agricultural implements, and religious ceremony artefacts. Though both species are put to similar uses, a systematic comparative account of their physical and mechanical properties are not yet available to determine to what extent *P. ritchiei* can substitute *P. stocksii* in the furniture and construction industries. *P. ritchiei* is not known to be used at commercial scale until now and is not listed by NBM due to a lack of studies and a scarcity in supply of species.

Fig 3. *P. ritchiei* grown in the home gardens in Mannarkad (A) and Nilambur (B) in Kerala

Table 2. Similarities of *P. ritchiei* to *P. stocksii*

Characters	*P. ritchiei*	*P. stocksii*	Reference
Culm solidness	Completely solid	Nearly solid with narrow lumen to completely solid culms	Beena *et al*., 2007; Kumar, 2011
Rhizome	Sympodial	Sympodial	
Thorns present	Thorn less	Thorn less	
Spikelets	1-2 florets	1-2 florets	
Anthers	6, yellow	6, yellow	
Fruit	Caryopsis	Caryopsis	
Inflorescence	Panicle	Panicle	

Table 3. Differences between *P. ritchiei* and *P. stocksii*

Characters	*P. ritchiei*	*P. stocksii*	Reference
Culm colour	Yellowish green	Dark green	Muktesh K., & Stephen,S. 1995; Beena *et al*., 2007; Kumar, 2011; Rane *et al*., 2016
Culm surface	Covered with velvet yellow tomentum when young but remain smooth at maturity	Covered with white hairs when young, while glossy and glabrous at maturity	
Culm wall thickness	Solid culm	Thick walled with narrow lumen to solid culms	
Culm height	6-8 m	7-12 m	
5th internode Diameter	20-25 mm	30-35 mm	
Internodal length	25-30 cm	30-40 cm	
Number of internodes	25-30	35-40	
Culm sheath	Covered with golden brown hairs	Covered with reddish brown hairs	
Culm sheath auricle	Absent	Well developed with oral setae	
Filaments	Monadelphous	Free	
Stigma	Single, White plumose	Single, purple plumose	
No. of new shoots per year	Approximately 14	Approximately 6	
Culm solidness	Completely solid	Partially to completely solid	
Rhizome neck	Long neck pachymorph	Short neck pachymorph	
Seed set	Seed set with viable seeds	No seed set	

Fig 4. An entire clump of *P. ritchiei* (A); A clump of *P. stocksii* (B); Solid culm of *P. ritchiei* (C); Thick-walled culm with narrow lumen in *P stocksii* (D); Culm sheath of *P. ritchiei* (E); Culm sheath of *P. stocksii* (F).

Floral morphology

The inflorescence of *P. ritchiei* is a large panicle with dense globular heads measuring 5-6.5 cm in diameter. Each spikelet-bearing head grows from the nodes of branches. The spikelets are lanceolate in shape and have one or two reduced flowers or florets which are fertile and sterile mixed. The spikelets are glabrous, mucronate, and spinose, measuring 1.5- 2 cm long and 0.2 cm wide. Each spikelet contains 2-3 sterile glumes. A linear-lanceolate, glabrous lemma with a coriaceous base is present in fertile glumes. The lemma is 1.4-1.6 cm long, with a mucronate, spinose tip. Palea is membranous and glabrous, measuring 1.2-1.4 cm in length, being shorter than the lemma. There are six monadelphous stamens with anthers measuring 0.3-0.6 cm in length. A glabrous, ovate ovary with a single curved feathery stigma over a 1.2-1.4 cm long style is found in the pistil. The fruit is a caryopsis, which is linear-oblong with a faint groove and a small beak and shows hypogeal germination (Unnikrishnan, 2003).

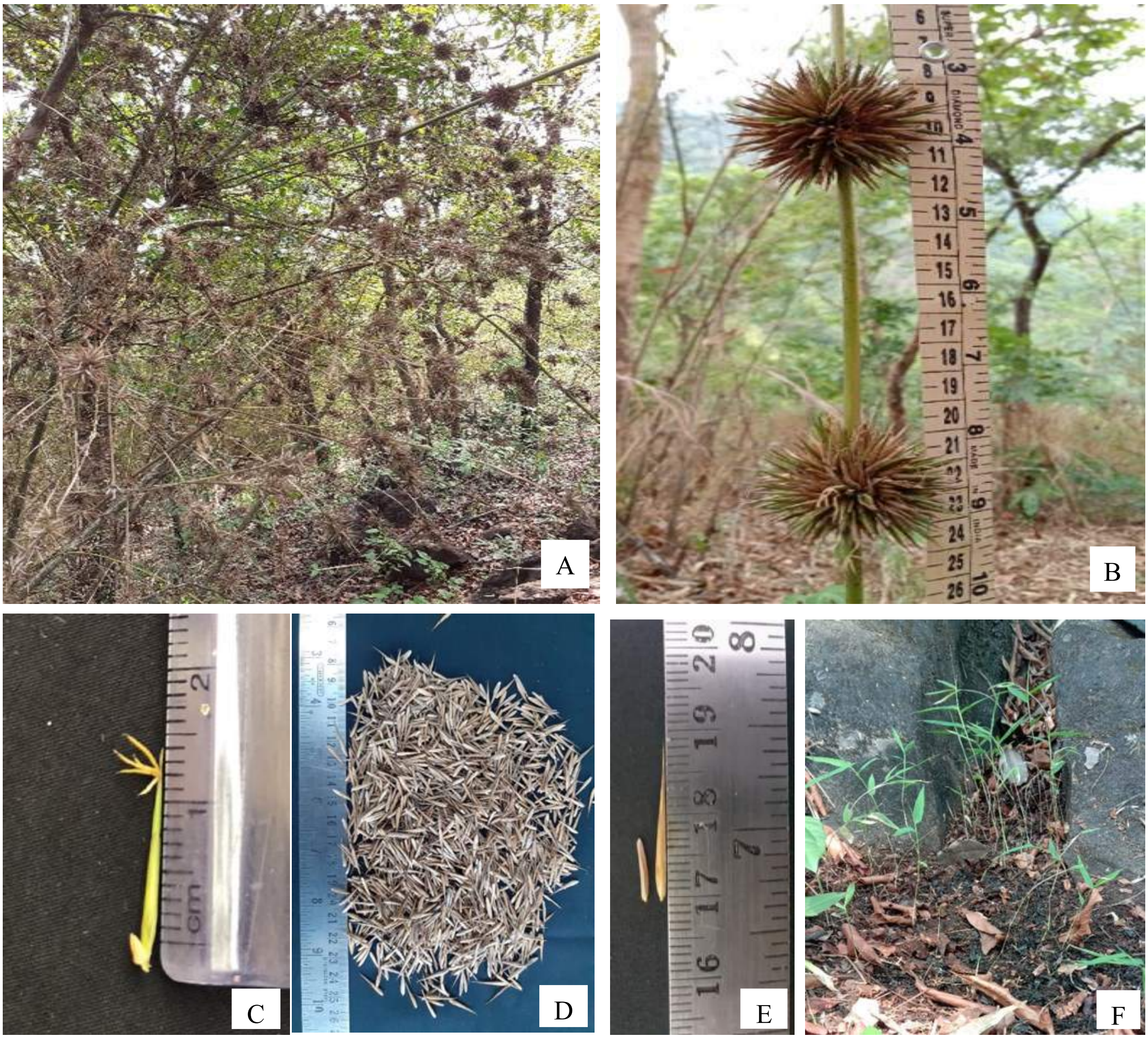

Fig 5. *Pseudoxytenanthera ritchiei* Branches bearing inflorescence (A); Spikelets on head (B); A single spikelet (C); Caryopses/Seeds (D); Dehusked seed (E); Seedlings.(F) .

Flowers open around 9 a.m. and exhibits protogyny, where gynoecium matures 3-4 days before androecium which is an adaptation to promote cross pollination. Anthers emerge during anthesis and dehisce by 11 a.m., releasing a large amount of pollen. Pollen grains are monoporous with 98% viability and a high germination percentage. The species has good seed production, and the flowered clumps dries after the seed set (Beena *et al*., 2007).

Flowering history

As the majority of bamboo species are monocarpic, documentation of the flowering years is crucial for understanding its reproductive biology and flowering cycle. It also aids in the study of the species' regeneration potential in the natural population following seeding. *P. ritchiei* flowers sporadically in the summer, while gregarious flowering is observed on rare occasions. During gregarious flowering, flowering begins synchronously in all clumps germinated from a common mother clump, even if they are geographically separated; thus, locating flowering clumps aids in the identification of different cohorts of populations within its distribution range (Thapliyal *et al*., 2015). Furthermore, it is critical if a seedling population of known genetic age is to be be raised. The use of these seedlings as planting stock helps in predicting the flowering year in advance (Seethalakshmi *et al.*, 2007).

The first available report of the flowering in *P. ritchiei* is for the year 1852, from Kala Nuddi, Bombay (Blatter, 1929). The author had further reported the flowering in Satara Ghat in the year 1870, North Kanara (1884, 1889), Mahabaleshwar, and Ahmednagar (1892) in the present-day Karnataka and Maharashtra states (Blatter, 1929). The species exhibits both sporadic and gregarious flowering. Kadambi (1949a) reported gregarious flowering of the species in the years from 1943 to 1945 in Aramballi, Agumbe, Balehalli, Chokkadabyle, Kunda, Sirur, and nearby areas of Shimoga forest division in erstwhile Mysore state British India. The species blooms once in around 15-20 years (Maheshwari *et al.*, 1976). Kulkari *et al.* (2001) reported the gregarious flowering of *P. ritchiei* in 1999 at Rajgad Fort in Pune, Maharashtra, after a period of fifty-two years. Beena *et al.* (2007) studied the floral morphology and post-flowering behaviour of the species. A profuse seed set followed by the death of the clumps was noted in the study. The study also mentioned the flowering cycle to be around eighteen years as the species flowered in year 1987 and next in the year 2006 in the same location at Nilambur in Kerala state. The presence of two cohorts was also identified in the study. The latest report on the flowering of *P. ritchiei* is from Nilambur in 2007 by Seethalakshmi *et al.* (2007). Table 4 provides a summary of reports on the available flowering events in the population of *P. ritchiei* .

Table 4. Records of flowering of *P. ritchiei*

Year of Flowering	Location	Reference
1852	Kala Nuddi	Blatter, 1929
1870	Satara Ghat	Blatter, 1929
1884	North Kanara	Blatter,1929
1889	North Kanara	Blatter,1929
1892	Mahabaleshwar, Ahamednagar	Blatter,1929
1943-44	Agumbe, Ballehalli. Chokkadabyle, Kunda, Sirur, Shimoga Division	Kadambi, 1949
1945	Aramballi	Kadambi, 1949
1947	Velhe Taluk of Pune District of Mahashtra	Kulkarni *et al.,* 2001
1957-58	Koyna Valley of Satara Districts of Maharashtra	Desai and Subramanian, 1980
1987	Marutha, Ambumala (Nilambur)	Seethalakshmi and Kumar, 1998; Beena *et al*., 2007
1995	Silent Valley	Sequiera and Kumar, 1995
1999	Near Rajgad Fort in Velhe Taluk of Pune District of Mahashtra	Kulkarni *et al*., 2001
2001	Nilambur Forests	Unnikrishnan, 2003
2006	Marutha, Vazhikadavu, Nilambur	Beena *et al*., 2007
2006-07	Nilambur	Seethalakshmi *et al*., 2007
2022	Nilambur Forests	Author's unpublished work

Propagation

Kuruvila (2017) provides reports on the vegetative propagation via stem cuttings and offset planting in *P. ritchiei*. The experiment was carried out over three seasons (summer, winter, and rainy), with culm cuttings from the top, middle, and bottom portions treated with varying concentrations of phyto-hormones such as IBA (Indole butyric acid) and NAA (Naphthalene acetic acid). Only cuttings taken from the basal part of the culm without growth hormones (control) produced the most rooting (31%) in the summer season. However, this rooting percentage was insufficient for adopting the technology for propagation of the species on commercial scale.

Sankar and Muralidharan (2017) investigated the in-vitro propagation of *P. ritchiei*. The effect of various cytokinins (Meta-topolin), Thidiazuron, 6-Benzyl-adenine Kinetin) on axillary shoot proliferation of nodal explants was studied, and the results revealed that meta-topolin overcomes season-induced dormancy of buds and has high axillary shoot proliferation rate. However, this technology is not yet adopted for the large-scale production of in-vitro plantlets of the species.

Offset planting is a suitable option in propagation of *P. ritchiei*. But the method is not feasible for large-scale plantations as the number of offsets that can be collected per clump is only one or two. This method, however, can be used for establishing mother plant collections of the species (Fig. 6.A). Rhizome banks can also be used for this purpose. Rhizome banks are nurseries that collect and maintain plants from seed sources to supply certified rhizomes of known age, which can also serve as a certified seed source in the future (Chandran, 2008). *P. ritchiei* has sporadic and gregarious flowering with fertile seeds, hence seed propagation is also a viable method (Fig. 6.B). Plants developed from seeds can be subjected to Macro-proliferation for further multiplication of the planting stock.

Fig 6. Various Propagation Methods: Plants developed through offset propagation method (A); Plants germinated from the seeds (B).

Fig 7. *P. ritchiei* as a multipurpose resource; A goat shed made of *P. ritchie* poles (A); Drying rubber sheets over *P. ritchie* poles (B); Shed for storing firewood (C); Trellis for bittergourd (D).

Ecosystem services

The ecosystem services provided by the bamboo species are enormous. Bamboo has over 1000 documented uses, which include both economic and ecological (Liese and Kohl, 2015). Bamboo is an important non-timber forest product (NTFP) and an important part of forestry, but it is also found in farmlands, home gardens, riverbanks, and urban areas. These are valuable assets that contribute not only to poverty reduction and economic development, but also to environmental conservation (Paudyal *et al*., 2019).

Provisioning services

Bamboo forests provide various provisioning services such as food and fodder production, medicinal and bioenergy sources, supply of construction and other raw materials etc., and are one of the most economically important plant groups (Paudyal *et al*., 2019). The recent decline in timber production from natural forests, combined with the increasing population, necessitates the need for alternative sources of wood (Mustafa *et al*., 2021). Bamboos are traditionally used as a building material for rural housing and food, as well as in the manufacturing of furniture and handicrafts. *P. ritchiei* is one such species of huge utility potential. *P. ritchiei* is commonly used by fishing communities in Maharashtra and Goa (Deshmukh *et al*., 2002). It is also a preferred species for constructions in these areas, such as for making temporary pavilions for religious and social functions, as rafters for roofing cattle sheds and extensions to existing houses (Nagi, 2002). However, the species has not been thoroughly explored as a source of renewable construction material.

Bhanadri (1981) reported *P. ritchiei* as a suitable raw material for the production of wrapping, writing, and printing paper based on proximate chemical analysis, studies on fibre dimensions, and experimenting with yield and strength properties of unbleached and bleached kraft pulp sheet. According to the authors ongoing research and related field work on *P. ritchiei,* it is a species that is highly favoured by people for a variety of domestic purposes. It is used in crafting of umbrella handles, walking sticks, lathi (baton), furniture, and support for crops such as betel and grapevine, trellis for vegetables, cattle sheds, and in constriction of semi-permanent housing structures or temporary sheds for storing firewood, fodder or agri -culture produce. It is also used to dry rubber sheets by hanging them on the *P. ritchiei* poles (Fig. 7).

Until 2005, approximately 25-50 metric tonnes of *P. ritchiei* culms were sold each year from Nilambur forests in Kerala state, which is reported to have been used as walking sticks by pilgrims along the treks to the Velliangiri temple on a hill in Coimbatore, Tamil Nadu state (Kumar *et al*., 2009). It is estimated that one tonne dried bamboo poles comprised 1000-2000 numbers of ten-foot-long poles (Maheshwari *et al*., 1976). In Mysore, it was used to make pulp (Fernandez, 1967). It is also used by farmers in Tamil Nadu as support for betel cultivation (Krishnankutty and Mammen, 2009).

Juvenile shoots of bamboo are rich in nutrient components such as fibre, minerals, proteins, and carbohydrates while low in fat and sugars, making them both a nutraceutical and a health food (Chongtham *et al*., 2011). People in Uttara Kannada and the South Konkan region of Maharashtra consume the tender shoots of *P. ritchiei* as a vegetable (Chandran and Gadgil, 1993). Narvankar *et al*. (2020) reported seven dishes made with *P. ritchiei* shoots, noting that the species can be stored in the brine solution for a year. The nutritional profile of the species is unknown, so proximate analysis is to be conducted to identify the nutrient and mineral composition in the young shoots.

Regulating services

Bamboo brakes provide numerous ecological benefits to communities both within and beyond local areas, including the restoration of degraded lands through sediment retention, landslide control through a dense network of roots, rhizomes, and leaf litter, as shelter-belts to protect against strong winds and storms, stream bank stabilisation, ground water recharge, and carbon sequestration. The action of the leaves and bark is also known to improve air quality. The carbon sequestration potential of bamboo is being recognized in climate change mitigation due to its fast growth rate and high annual regrowth after harvesting. It can be considered as a potential carbon sink when the harvested culms are converted into durable products (Yuen *et al*., 2017; Paudyal *et al*., 2019).

Studies on assessing the ecological importance of *P. ritchiei* in Kerala Forest ecosystems are few. Research shows that the total carbon sequestration potential of the species is around 26 Mg ha^{-1}, which is low when compared to three-year-old *Dendrocalamus strictus* and five-year-old *Bambusa bambos*. However, it is higher compared to 24-year-old *Anthocephalous chinensis* and eight-year-old *Azadirachta indica*. This observation suggests that *P. ritchiei* can store a significant amount of carbon in biomass and soil, making it an effective carbon sink. The biomass yield is nearly 58.11 Mg ha^{-1}. Here, above-ground components (stem-51%, leaves + branches-9%) contributed more to the biomass than below-ground components (rhizome-38%) (Kuruvilla *et al*., 2015; Jijeesh *et al*., 2020).

Litter production studies on *P. ritchiei* in the Kerala part of the western Ghats reveal a triphasic pattern, with the highest litter fall occurring in February and the other two phases occurring in May and December. The average litter production in *P. ritchiei* is about 2.842 t $ha^{-1}year^{-1}$, which is higher than that of small clump-forming bamboos like *Ochlandra travancorica* but lower than that of large and medium clump-forming bamboos like *B. bambos*, *B. balcooa*, and *B. pallida*. Carbon, nitrogen, calcium, phosphorus, potassium, and magnesium are the most abundant nutrients in biomass of *P. ritchiei*. Most nutrients are locked in the stem compared to the rhizome, leaves, and roots. It takes approximately 77 days to decompose 50% of the litter, with nutrient release occurring in the order N = Mg > K = Ca > P (Kuruvilla *et al*., 2016; Jijeesh *et al*., 2021).

Considering all the benefits provided by the species, it is reasonable to conclude that including this species in the Clean Development Mechanism, forestry projects, and land restoration projects to propagate at suitable sites will help improve ecosystem services.

Threats in natural habitat

P. ritchiei is classified as a rare bamboo species in states such as Kerala and Maharashtra and is listed among the threatened plants of India (Kumar *et al*., 2009; BSI ENVIS; NBRI, 2019). In 2020, Jijeesh *et al*., reported that *P. ritchiei* has been reduced to a conservation-dependent status in the Nilambur forests of Kerala, where the species was once found in abundance (Kumar *et al*., 2009). As the species is sparsely distributed in the landscape it is possible that natural population is reducing in response to various abiotic and biotic threats (BSI ENVIS; Kumar, 1991; Bahadur and Jain,1981; Kumar, 2009). According to an estimate the bamboo-bearing area in Kerala has seen a whopping 30 percent decline from 3484 sq km in 2017 to 2404 sq km in 2021 (ISFR 2017; 2019; 2021). Field studies carried out by the authors identified animal interactions, invasive species, deforestation, unsustainable harvesting, and diseases as the major threats affecting the survival of the species. Gregarious flowering and climate change could very well aggravate the situation further (Kuruvilla, 2017).

Wild boars dig up and eat the rhizomes during the rainy season as well as during the dry season when other more palatable food is not available. Rats, porcupines, squirrels, and monkeys gnaw the young rhizomes and tender growing shoots. Deer and other animals trample the young seedlings while browsing.

Wild elephants pull down and destroy entire clumps, resulting in stunted growth in areas where they live (Fig 8. A) (Kadambi, 1949). Loosely spaced culms and non-thorny nature of the clump are the major reasons for preference of this species by browsers over thorny bamboo species like *Bambusa bambos*. Invasive species such as *Chromolaena odorata* and *Mucuna bracteata* entangle the entire clump and cause it to dry (Figs. 8C and D). The aggressive spread of the invasive species also affects in the regeneration of the bamboo species. Both the expansion of human settlements and shrinking and encroachment of forest habitats, contribute to the further decline of population.

Fig 8. Threat factors affecting growth of *P. ritchiei*: Arrested growth of clumps due to disturbance by elephants and browsing animals (A); Unsustainably harvested culms gathered for selling (B); *Chromolaena odorata* entangling *P. ritchiei* clump (C); *Mucuna bracteata* spread on *P. ritchiei* clump (D)

Another cause of the forest resource depletion is over-exploitation. Between 2011 and 2014, a total of 2,39,999 *P. ritchiei* poles were extracted from the Nilambur forests (Working Plan, Nilambur North Forest Division, 2015-2025). Because of the wide application potential of the species, tribal people with permission use it widely and sustainably for their basic needs, whereas local people collect it illegally from nearby forest areas without permission. The major issue with illegal collection is that basic rules of sustainable harvesting is not observed, resulting in clear felling of both matured and immature culms. As no culms are retained, the clump either dries up due to a lack of nutrients for new culm emergence or only unhealthy thin culms emerge with the onset of monsoon.

P. ritchiei has been reported to have foliage diseases such as leaf rust, zonate leaf spot, and tar spot. The rust fungus *Dusturella divina*, causes the rust infection which appears as minute flecks on upper surface of leaves. Severe infection causes leaf necrosis and abnormal leaf fall. The fungal genus *Dactylaria* causes zonate leaf spot. Infection appears on the leaves of lower branches as minute greyish brown spots that enlarge to form a large zonate spot. The tar spot disease in *P. ritchiei* is caused by the fungal genus *Phyllachora.* Infection appears as small yellowish-brown lesions on the lower surface of the leaves, which spread to form circular spots. Application of appropriate fungicides at proper dosage and adoption of good nursery management practices can reduce the severity of disease outbreaks in nurseries and plantations (Mohanan, 1994).

Because of such continuous disturbances and dispersed distribution, the regeneration rate is very slow in the species. Field surveys conducted by the authors during 2022 and 2023 confirmed the shrinking distribution range of *P. ritchiei* over the past ten years. Appropriate strategies are to be developed to ensure the survival of the species in its native habitat, as well as to increase plantation outside of forests, which will reduce the pressure on existing natural populations (Jijeesh *et al*., 2020).

Current trends in policy and trade

Large-scale extraction from the forests and subsequent resource depletion compelled the Kerala government to impose a ban on harvesting of *P. ritchiei* in 2005 (Krishnankutty and Mammen, 2009). A subsequent field study on the conservation and sustainable utilization of the species revealed that, while the regeneration status was satisfactory, commercial harvesting should be encouraged only after five years (Kumar *et al*., 2009). Adivasi Vana Samrakshana Samiti (AVSS) is now in charge of cutting and collecting *P. ritchie* poles. The government has allotted permissions to collect species to the traditional forest dependent and forest dwelling communities belonging to the Scheduled Tribe and Scheduled Caste communities. Members of the communities are permitted to collect mature culms under the strict supervision of AVSS.

Fig 9. A. Transfer of *P. ritchiei* poles from cutting site; B. Harvested poles stacked for sale and utilisation; C. *P. ritchiei* poles loading for transportation.

Since 2014, permission has been granted in Nilambur North Forest Division for controlled extraction of 40,000 culms per year to maintain a safe stock and clump regeneration. Currently, harvesting *P. ritchiei* provides no major economic benefit to forest-dependent communities or the state, but traders profit handsomely. One reason for this is a lack of local value -addition or product diversification and thus a lack of demand for the species in Kerala. In 2022, permission was granted for collection of 40,000 culms of *P. ritchiei* for the sole purpose of providing tribal employment (Fig. 9). A trader from Tamil Nadu was awarded the tender at Rs. 20 per pole of approximately 5.4 m in length. One bundle was made up of 20 such poles. The tribal cutter is paid Rs.18 per pole, while VSS received Rs.2 per pole (Working Plan, Nilambur North Forest Division, 2014-2024; Surveys conducted for the study).

Commercial cultivation potential of the species

There are currently no large commercial plantations of *P. ritchiei* in Kerala like that of *Thyrsostachys oliveri* or *P. stocksii* (Fig. 10), but small scale planting is practiced by farmers in their home gardens (1-2 clumps) near forests. Krishnankutty and Mammen (2009) investigated the markets and employment generation in the harvesting of *P. ritchiei* from the Nilambur forest from 1998 to 2004. Prior to the ban (1998-2004), the average amount of culms collected from Nilambur forests was 570 metric tonnes per year, providing 3107 worker days per year. The tribal household could not rely on *P. ritchiei* harvesting for income because the employment was both marginal and seasonal. Despite the fact that *P. ritchiei* was harvested from Kerala forests, only 26% of it was used within the state, with the remaining quantity being transported to major markets in Tamil Nadu. Major retail bamboo depots in Tamil Nadu were located in Salem, Coimbatore, Athur, Anthiyoor, Nadupuni, Thirissinapilly, Rasipuram, and Chennai (Working Plan, Nilambur South Forest Division, 2014-2024). *P. ritchiei* from Kerala (Kerala erankol) was in high demand in the Tamil Nadu market because it is tough, as strong as cane, durable, has a uniform diameter throughout the culm, and is easy to handle, bundle, and transport. However, as the availability of the species decreased as a result of the ban, Tamil Nadu markets began selling 'Andhra erankol' (*Pseudoxytenanthera monadelpha*) as a substitute, which is not as durable as Kerala erankol and has a narrow hole at centre of the pole in contrast to Kerala Erankol which has a fully solid pole (Kumar *et al*., 2009). Thus, market demand and widespread acceptance of the species raise the possibility of cultivating *P. ritchiei* outside of forest areas to reduce pressure on its natural population in the forests. *P. ritchiei* can be planted as a border crop in home gardens, agroforestry cultivations, and reforestation programs. This will ensure a steady supply of resources for the market and an additional income for farmers.

Data gaps-future research and development needs

Recent biotechnology advances paved the way for genome-level explorations in bamboo, which resulted in the release of the Moso bamboo genome sequence in 2013 (Ramakrishnan *et al*., 2020). This breakthrough in molecular research can be used to uncover many

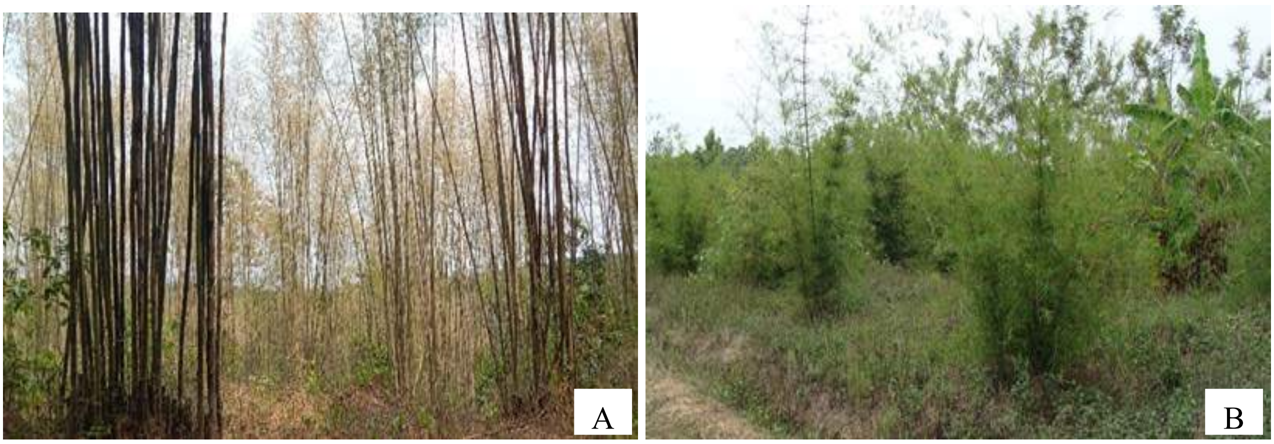

Fig 10. Commercial plantation of *Thyrsostachys oliveri* in Palakkad, Kerala (A); Commercial plantation of *P. stocksii* in Maharashtra (B).

intriguing aspects of bamboo biology, such as the molecular mechanism underlying monocarpic behaviour, rapid growth, broad adaptation potential, and so on. Furthermore, molecular studies in bamboo are essential for accurate taxonomic identification, assessing genetic diversity within and between species, analysing genetic distance and relationships between species, identifying distinct accessions for breeding purposes, and also for genetic improvement (Yeasmin *et al*., 2015).

It is critical to correctly identify and characterize a species in order to conserve and prevent the loss of the valuable resource (Khairi *et al*., 2020). Bamboo classification based solely on traditional morphological taxonomy is unreliable because environmental conditions influence most vegetative characters, and obtaining an inflorescence for identification purpose is hard to come by as the flowering time of the species is unpredictable (Zhao *et al*., 2015) all these warrants molecular identification of bamboo.

The genetic makeup of a species determines its adaptability to an environment, so discovering genetic diversity within the species populations is critical for conservation (Bhandari et al., 2021). Several molecular markers, including Restriction Fragment Length Polymorphism (RFLP), Randomly Amplified Polymorphic DNA (RAPD), Amplified Fragment Length Polymorphism (AFLP), Inter Simple Sequence Repeats (ISSR), and Single Nucleotide Polymorphism (SNP), are now being used in deciphering genetic diversity of bamboos (Yeasmin *et al*., 2015).

Molecular studies can also be used for the genetic improvement of bamboos, such as increasing productivity or other desirable characteristics. The identification and characterization of trait-specific genes that control economically important characteristics such as lignin and cellulose content, disease resistance, and so on, can be extremely beneficial to genetic improvement programs in bamboo (Thakur *et al*., 2016).

Molecular research on *P. ritchiei* is in its early stages, and more research is needed in this area. Cytological studies on *P. ritchiei* reveal that the species is hexaploid with a basic chromosome number 12, 2n = 6x = 72; x=12 (Mathu *et al*., 2015). Waghmare and Bagde (2012) used PCR-RAPD to conduct a comparative genetic analysis of *P. ritchiei* with three other bamboo species, *Bambusa bambos*, *P. stocksii*, and *Dendrocalamus strictus*, in the Ratnagiri district of Maharashtra. For RAPD PCR amplification, five decamer primers were used. 23 of the 35 loci were polymorphic, indicating a polymorphism rate of 65.71%. A similar study conducted by Waghmare and Bagde (2013) among 4 bamboo species (*B. bambos, P. ritchiei, P. stocksii, D. strictus*) in the Raigad and Sindhudurg districts of Maharashtra resulted in 65.79 % and 83.78% polymorphism respectively. The RAPD profile in this study revealed many common bands in *P. ritchiei* and *P. stocksii*, which could be attributed to the lower genetic distance between the species due to their shared genus.

Apart from the molecular studies major gaps were identified in the post flowering behaviour of *P. ritchiei*. There are studies in the literature that document the flowering (Table 4), as well as the reproductive biology of *P. ritchiei* (Beena *et al*., 2007), however studies on the seed morphology, seed quality, longevity, storage, or seedling growth are wanting. This call for research on the seed behaviour in *P. ritchiei*. Although age information is available in the literature, it is primarily based on a limited number of observations and memory of local informants (Kulkarni *et al*., 2001). Thus, there is a need for carrying out systematic recording of the flowering in the natural population of *P. ritchiei* and maintaining of collections in the bambusetum to obtain accurate information on the flowering cycle.

Studies to investigate and record the entire geographic distribution of the *P. ritchiei* throughout the Peninsular India must be conducted while also evaluating its conservation status (Rao *et al*., 2019). More research on the species are also required for quality planting stock production, identification of suitable habitats for future introduction, large-scale cultivation for ensuring continuous supply of the raw materials, and exploration of its market and utility.

Conclusions and recommendations

According to ISFR (2021), there has been a continuous reduction in extent of bamboo-bearing areas in Kerala since 2017, necessitating immediate action for the conservation of the existing population and assisted regeneration. *Pseudoxytenanthera ritchiei* is one such species that enjoyed wider distribution but has now been shrunk to scattered patches as small bamboo groves. Loosely spaced, thornless, and easily accessible nature of the species drew threats from both browsing animals and humans. The species was once in high demand on the market and was harvested and exploited on a large scale from Kerala forests, causing the population to decline. As an ecologically and economically significant species, various propagation methods must be encouraged to meet the demands for high-quality planting material. Culm cutting and tissue culture techniques must be standardized and commercialized. A germplasm collection with individuals from all existing natural locations should be maintained, and diversity studies to identify distinct genotypes must be conducted. This collection could also be used as a seed source and rhizome bank in the future. Multi-locational trials or ecological niche modelling can be performed prior to distributing planting material to select suitable sites for maximum productivity. Forest departments should maintain captive plantations as model plantations, and forest nurseries should serve as a repository of quality planting stock. Apart from encouraging large-scale propagation, steps must be taken to conserve the species in its natural habitat to prevent loss of genotypes. The species may be planted along river banks, marginal and community owned lands and planted as part of the afforestation programmes to improve resource availability and for providing ecological benefits such as carbon sequestration and soil nutrient replenishment.

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