The enigma of leaf size and plant size in bamboos

There are about 1030 species of woody bamboos (tribe Bambuseae, family Poaceae) in the world grouped under ca. 77 genera[1]. The Old World harbours 60% of the world's bamboo (ca. 57 genera, 620 spp.). In the New World, they are highly concentrated in Central and South America, but poorly represented in North America (two species). *Arundinaria* is the only genus common to both the Worlds[1,2]. *Neurolepis elata* (Kunth) Pilger [= *Neurolepis nobilis* (Munro) Pilger] and *Neurolepis glomerata* Swallen, found in the New World possess the largest leaf blades in the grass family[3]. During our bamboo explorations in the forests of Kerala, we came across a few clumps of the reed bamboo, *Ochlandra* Thwaites with unusually large leaves. This prompted us to draw a comparison of the leaves of *Ochlandra* with those of *Neurolepis* Meissner.

We estimated the leaf area from the linear measurement of leaves (= leaf blades) using the equation $A = 0.905\,LB$, where L is the length of the leaf and B the breadth of a point midway along the length[4]. Linear measurements were gathered from two sources: (1) from the Online World Grass Flora[5] and (2) from the fields, i.e. the *Ochlandra*-growing regions of Kerala. From the former, linear measurements of leaf blades of all bamboo species having length 20 cm or more were gathered (Table 1). For the latter, field surveys were conducted for the collection of larger leaves and their measurements were noted discarding the length of acumen (Table 2). The leaf area of each species was estimated using the higher values of L and B in the case of measurements obtained from the Online World Grass Flora[5] (as the aim was to find leaves with maximum area) and from actual length and breadth of larger leaves in the case of natural stands. From the above data, we prepared a list of species in descending order of their leaf areas (Table 1).

According to our estimation, the bamboo with the largest leaf is *N. elata* (Kunth) Pilger, which is in agreement with Soderstrom[3]. *N. elata* is distributed in the New World in Ecuador in the Paramo forest at an elevation of 2700–3500 m. The leathery leaf blades of this species grow up to 5 m long and 30 cm wide[3,5], with leaf area of 13,575 cm^2. Endemic to Ecuador, it occurs only in 15 subpopulations apparently restricted to the Parque Nacional Podocarpus. The species is considered endangered because of its small geographical range and the destruction of its habitat[6]. The genus *Neurolepis* Meissner (ca. 21 species)[2] occurs on mountains at high elevations between 2000 and 4300 m, from Costa Rica and south of Trinidad along the Andes to northern Bolivia. *Neurolepis aristata* is unique in being able to grow at the highest elevation of 4300 m (ref. 2). The plants grow in cool, moist habitats which prevail on the upper reaches of the Andes, in the dwarf or shrub forest in the Paramillo, as in the colder more arid páramo (the unique Andean vegetation formation between elevations of 3000 and 4000 m). In the páramo, the day temperature fluctuates greatly between 0°C (or below) at night and 18–20°C during daytime. The unbranched aerial culms and the thick, tough and long leathery foliage of the species are believed to be adaptations to survive the relatively rigorous environmental conditions[3].

The largest leaf blade collected by us in Kerala is that of *Ochlandra ebracteata*, which measured 63.1 cm in length and 14.5 cm in breadth (Figure 1) with a total area of 828.02 cm^2. Thus *O. ebracteata* represents the species with the sixth largest leaf among the world bamboos and the largest in the Old World (Tables 1 and 2), though it accounts for only 1/16th of the leaf size in *N. elata*. *Ochlandra wightii* (Munro) Fischer occupied the second position followed by *Ochlandra travancorica* (Tables 1 and 2). The linear measurements provided in Table 2 are the highest for any *Ochlandra* species reported so far, as the earlier record[7] was 40–60 × 10–12 cm. On drying, the leaves lose their length by 0.5–1 cm and breadth by 0.5–0.8 cm. *O. ebracteata* and *O. wightii* are endemic to southern Western Ghats and are reported only from the hilly tracts of the extreme southern region of Kerala (Thiruvananthapuram, Kollam and Pathanamthitta districts)[7]. Again, it is interesting to find that all large-leaved *Ochlandra* species are distributed in the southernmost part of peninsular India. The genus *Ochlandra* Thwaites (11 species) occurs from lower elevations up to 1500 m. Ten species are endemic to the Western Ghats, India and one is endemic to Sri Lanka[7–9]. Among these, *O. ebracteata*, *O. travancorica* and *O. wightii* bear larger leaves. Wherever the plants occur they grow gregariously forming impenetrable thickets. They generally occur under the shade of tall trees or in open patches in the hills and valleys. Each clump produces as many as 50–600 culms depending upon its age and soil conditions. On account of their large size, the leaves of the above species are used for thatching. Elephants feed on their leaves and young shoots,

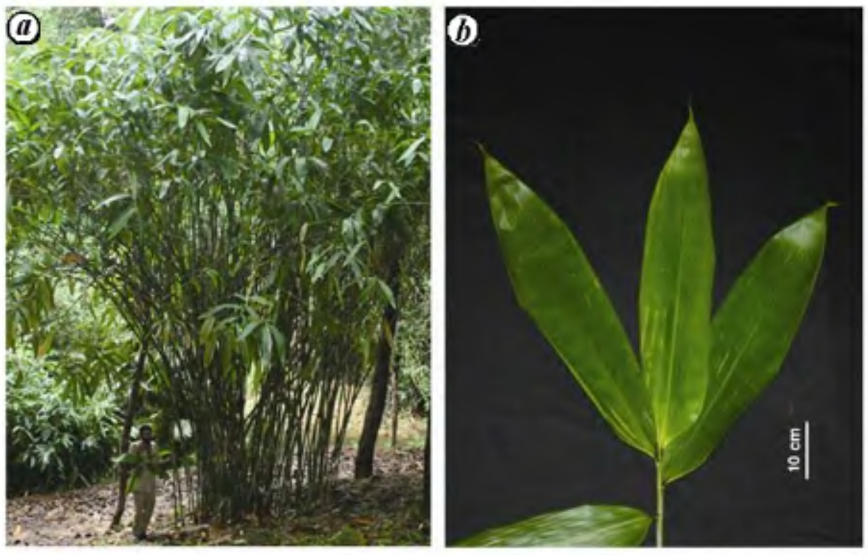

Figure 1. *Ochlandra ebracteata*. ***a***, Clump; ***b***, Twig with large leaves.

Table 1. Leaf area of top 15 world bamboo species in descending order

Species	Data source	Length × breadth (range; cm)	Length (L) (higher value; cm)	Breadth (B) (higher value; cm)	Leaf area (cm^2)
Neurolepis elata	The Online Grass Flora[5]	50–500 × 25–30	500	30	13,575
Neurolepis pittieri	The Online Grass Flora[5]	100–215 × 10–17	215	17	3307
Neurolepis virgata	The Online Grass Flora[5]	50–150 × 3–8	150	8	1086
Neurolepis angusta	The Online Grass Flora[5]	80–165 × 6–6.5	165	6.5	970.61
Neurolepis petiolata	The Online Grass Flora[5]	67–93 × 7–11	93	11	925.8
Ochlandra ebracteata	Collection No. 47865/1	See Table 2	63.1*	14.5*	828.02
Ochlandra wightii	Collection No. 47875/1	See Table 2	67.4*	13.2*	805.16
Schizostachyum arunachalensis	The Online Grass Flora[5]	30–48 × 7.5–18	48	18	781.92
Ochlandra travancorica	Collection No. 47876/1	See Table 2	59.2*	14.4*	771.49
Neurolepis glomerata	The Online Grass Flora[5]	150 × 4–5	150	5	678.75
Schizostachyum grande	The Online Grass Flora[5]	30–60 × 4–10	60	10	543
Indocalamus guangdogensis	The Online Grass Flora[5]	35–56 × 3.9–10.4	56	10.4	527.07
Ferrocalamus strictus	The Online Grass Flora[5]	30–55 × 6–9	55	9	447.975
Neurolepis aristata	The Online Grass Flora[5]	30–80 × 4–6	80	6	434.4
Dendrocalamus pachystachyus	The Online Grass Flora[5]	20–40 × 6–12	40	12	434.2

*Actual measurements of largest leaves.

Table 2. Linear measurement of *Ochlandra* leaves

Species	Locality	GPS co-ordinates	Collection number and date	Leaf length (cm) Av. ± SD (n = 10)	Leaf breadth (cm) Av. ± SD (n = 10)	Leaf length (cm) (highest value)	Leaf breadth (cm) (highest value)
Ochlandra ebracteata	TBGRI, Kerala[8], Acc.278	08°45.364′N 077°01.489′E	47865/1 16.9.08	62.34 ± 2.306609	13.74 ± 0.499333	63.1	14.5
	Kottoor, Kerala	08°35.086′N 077°08.932′E	47999 5.3.09	60.35 ± 2.635758	13.81 ± 1.094887	62	14.6
	Bonaccord, Kerala	08°40.270′N 077°09.188′E	47879 29.12.08	59.32 ± 4.812438	12.33 ± 1.686581	60.1	14.2
Ochlandra wightii	TBGRI, Kerala[8], Acc.286	08°45.269′N 077°01.571′E	47875/1 15.12.08	67.12 ± 1.392679	12.06 ± 0.945398	67.4	13.2
	Ponmudi, Kerala	08°44.214′N 077°07.209′E	47883 30.12.08	58.57 ± 7.397455	11.81 ± 1.502184	66	12.9
	Ponmudi, Kerala	08°45.497′N 077°07.133′E	47976 30.12.08	57.05 ± 4.828676	12.62 ± 0.543241	63.4	13.2
Ochlandra travancorica	Palode, Kerala	08°45.036′N 077°01.607′E	47876/1 15.12.08	55.5 ± 3.616014	12.51 ± 0.985957	59.2	14.4
	Palode, Kerala	08°45.335′N 077°01.454′E	47825/2 31.1.08	52.31 ± 3.64126	13.05 ± 1.002497	53.8	14.4
	Palode, Kerala	08°45.328′N 077°01.463′E	47826 31.1.08	53.86 ± 2.02934	13.35 ± 1.072121	55.5	13.8

Note: The specimens mentioned in column 4 are deposited in the herbarium of TBGRI, Thiruvananthapuram.

especially during the dry season[10]. In addition, the culms of these species are widely used in pulp, paper, plyboard and cottage industries.

Neurolepis species in the New World represent bamboos with the largest leaves in higher elevation (2000–4300 m), whereas *Ochlandra* species with the largest leaves among the Old World represent bamboos at lower elevations (0–1500 m). Strangely, both *Neurolepis* and *Ochlandra* species are short bamboos (< 8 m) in comparison with the tall species such as *Guadua angustifolia* Kunth and *Guadua chacoensis* (Rojas) Londono & Peterson, the largest bamboos in the Neotropics, and *Dendrocalamus giganteus* Wallich ex Munro and *Dendrocalamus brandisii* (Munro) Kurz, the largest in the Palaeotropics (> 30 m). Whether they occur at higher elevations where snowfall occurs (*Neurolepis* spp.) or at lower elevations (*Ochlandra* spp.), the plants have to trap as much light energy as possible. The large and leathery leaves help in the survival of the species under extreme conditions in the former, and to

establish a gregarious growth pattern despite browsing and commercial exploitation in the latter.

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ACKNOWLEDGEMENTS. We thank Prof. H. Y. Mohan Ram for taking efforts to improve the manuscript; Dr T. S. Nayar and Dr C. Sathish Kumar for helpful suggestions, and N. Salahudeen and K. Asokachandran Nair for assistance during fieldwork. The Western Ghats Cell, Planning and Economic Affairs Department, Government of Kerala is acknowledged for funding the work under the Western Ghats Development Programme.

Received 29 June 2009; revised accepted 31 August 2010

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Stationary magnetotelluric monitoring system for earthquake research in Koyna region, Maharashtra

Strong earthquakes usually lead to crustal scale deformations, which in turn are caused by the large stress accumulation over a long period of time (a few decades). The recent major devastating earthquakes in India – Bhuj earthquake in Gujarat[1], Jabalpur earthquake in Madhya Pradesh[2] and Latur earthquake in Maharashtra[3,4] – have changed the notion that stable continental regions of India are not prone to major earthquakes and have demanded more stable examination of the stress accumulation. Another factor of concern to the Indian earth scientists is the continuous seismic activity in the Koyna–Warna region of Maharashtra located near major reservoirs.

Continuous seismic activity in the Koyna–Warna region has drawn the attention of many earth scientists in India and abroad especially due to its active nature since 1963. After the first known main earthquake near Koyna on 10 December 1967, the activity continued around 0.1 million earthquakes of low ($M < 4$) magnitude earthquakes[5]. A few (190) high-magnitude ($M > 4$) earthquakes have also been reported from the Koyna–Warna region. Interestingly, these earthquakes occur in a small region of 25 × 10 sq. km. This region is also well-mapped for the existence of faults and has become an ideal site for initiating the earthquake-monitoring experiment to understand the physics of occurrence and also for protection. Many geophysical studies like GPS, gravity variation, pore pressure, radon gas leakage measurements, etc. have been initiated for monitoring the earthquakes. In this direction, magnetotelluric (MT) field measurements have also been taken up with an aim to develop a forecast model for earthquakes in the region. It is reported that seismic activity causes ionospheric

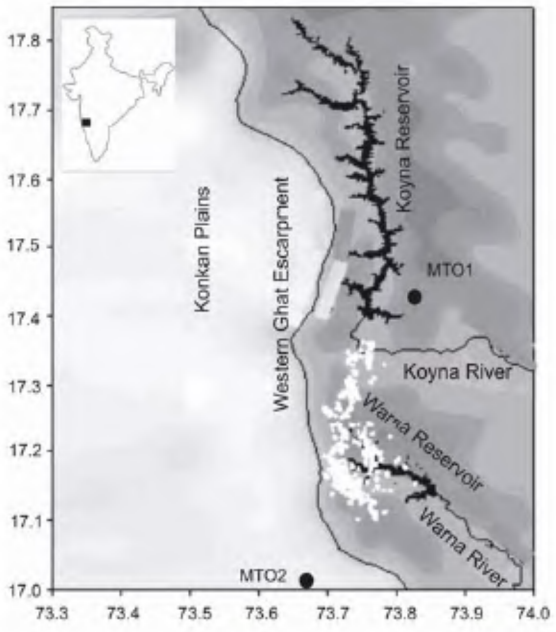

Figure 1. Location of the two magnetotelluric stations, MTO1 and MTO2, in Koyna along with locations of the two reservoirs – Koyna and Warna. Distribution of earthquake epicentres for 1996–97 in Koyna is shown as white dots. Sharp changes in the surface elevation with the Western Ghats in dark colour as a boundary can be seen.