BOTANICAL WONDER AT INDIAN INSTITUTE OF SCIENCE

[*Entada pursaetha* – Wonder Climber of Western Ghats]

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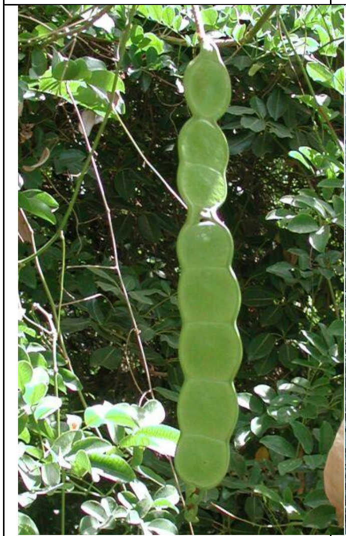
1.0 Summary

Morphological Characteristic of *Entada pursaetha*	
Synonym:	*Entada pursaetha* DC.; *Entada scandens* auct. non Benth.; *Entada monostachya* DC.
Vernacular name:	Hallekaayi-balli, Pallekaayi (Kannada)
Common name:	African Dream-nut, Elephant Creeper, Mackay Bean, Ladynut
Global distribution:	Tropical and South Africa, Sri Lanka, India to China, Malaysia to Australia
Flowering & Fruiting:	March to May
Habitat:	Common along river and stream sides of evergreen and semi-evergreen forests.
Ecosystem service:	Seeds eaten by Indian Giant Squirrel (*Ratufa indica indica*)
Uses - Food:	White kernels of seeds are edible**.**
Uses - Medicine:	Bark and seed used for ulcers, stem for skin diseases, seed used as stomach ache, anti-rheumatic, anti-inflammatory and dietary supplement. Seeds are known as African Dream-nut and used for hallucinatory effects by shamans of Africa.

Description: It is a gigantic climber with twisted angled stems. Bark brown and fibrous. Leaves dark green, bi-pinnate, leaf-rachis glabrous, grooved, ending in a bifid tendril, pinnae 2-3 pairs, leaflets 3-4 pairs, up to 9*4 cm, ovate-oblong, obtuse of emarginated at apex. Spikes up to 30 cm long, from the axils of upper leaves or from nodes on the leafless branches. Flowers in long axillary pendulous spikes, up to 30 cm long, from the axils of the

upper leaves or from the nodes on the leafless branches. Small, polygamous, pale yellow in colour. Calyx campanulate, 5-toothed. Petals 5, oblanceolate, free or slightly cohering. Stamens 10, free, shortly connate at base, exserted; anthers tipped with deciduous stalked gland. Ovary subsessile, many ovuled c. 8 or more; style filiform. Fruit a pod, huge, up to 2 m × 15 cm size, compressed, woody, 6-15 jointed; joints discoid or square. Breaking down into single-seeded segments, leaving the outer rim. Seed flat, round disc shaped, c. 5 cm in diam., smooth glabrous brown or purple in colour, testa very hard. Can survive lengthy periods of immersion in fresh water and sea water facilitating water dispersal and establishment close to streams and rivers and coastal forests.	
Source of seeds	Pod containing 14 seeds was collected from the evergreen Forest in Yellapur taluk, Uttara Kannada district, Western Ghats (latitude 13°55' to 15°31'N, longitude. 74°9' to 75°10'E) about 55 km from the Arabian Sea, at an elevation of 700-800 meters above sea level.
Climate at seed collection location	The region receives 450 cm or more annual rainfall, and during post monsoon period the wind speed is 8-10 m/s.
 	
Year of planting	1988 (planted seeds at seven locations and among these only the one planted near CES grew and spread in the vicinity of CES at Silver oak marg).
Planted by	T V Ramachandra
Pre-treatment	mechanical cracking of the hard testa, the seeds were kept in a coarse cloth bag and floated in pond water for about 20 days before sowing at seven locations in Indian Institute of Science campus.

Germination success	Of the 7 seeds sown, one buried in soil close to a tree of *Bauhinia purpurea* (Caesalpinioideae, Leguminosae) (adjacent to CES department) has grown into a liana, spreading its canopy on a miniforest of semi-evergreen tropical trees, in an area roughly equivalent to 1.6 ha.
Climate	In a dry subtropical environment, the receives about 800 mm annual rainfall and located at 918 m asl.

2.0 Introduction:

The Western Ghats refers to the unbroken chain of hills (of which Palakkad gap is an exception) running in the North-South direction for about 1600 km parallel to the Arabian Sea from river Tapti (22˚26‟N) to Kanyakumari (about 8˚0‟ N) and extends zonally from 72˚55‟E to 78˚11‟ E covering an area of about 1, 64,280 km^2. It is one of the 35 global biodiversity hotspots and the habitat to a large number of endemic plant and animal species. These species face threat of vulnerability and extinction due to habitat loss with changes in weather and climate. Climate in the Western Ghats varies with altitudinal gradation and distance from the equator. Annual rainfall in the region with proximity to the sea averages to 3000-4000 mm.

The tropical rain forests and other humid forests are known for their exceptional richness for various species of giant climbers, the lianas, than the temperate or drier tropical forests. Liana are conspicuous structural component of tropical forests and make about one fourth of the woody plant diversity of peninsular Malaysia, rated as high as South American forests in liana richness (Appanah et al., 1993; Bhat, 2014). The dark canopies in such forests permit only scanty light into the forest interior, as diffused light and sun-flecks. In the competition for light the trees grow taller until they reach the canopy or sub-canopy levels and many those requiring full exposure to sunlight emerge above the general canopy as towering giants. The plants that keep away from this race for light are adapted to the dimness of the forest floor, which is not as rich in herbs, but may be covered with seedlings and saplings of the trees as well as of the lianas. Evolution has its own ways in such situation, as one has to look up towards the crowns of trees to see bulk of the rain forest herbs clinging on to branches and trunks as epiphytes, along with wreath of mosses and ferns. It is no exaggeration to say that in the rain forest one has to look up than on to the floor for the herb layer diversity. Although woody and having own well developed root systems the lianas need physical support to hold on and climb up to reach heights to expose their foliage to the sunlight. In the younger stages lianas are more shade tolerant, have more tender stems which coil over support, which may be the trunks and branches of trees. With the passage of time their main stems and branches turn stronger and woodier, yet the lianas cannot stand on their own. Growth is slow for these 'climbing trees' while in the deep shade. The growth happens prolifically in tree fall gaps. Coiling on any support nearby, from tree saplings to larger trees, the lianas in gaps grow in tangles, their long slender shoots linking trees like cables, turning thicker and woody and assuming diverse forms like ropes and cables, or suspended in the air in huge loops or in serpentine coils. Many trees are affected in the stranglehold of lianas, their trunks misshapen, growth stunted, the weaker collapsing in a mass unable to bear the weight of these climbing trees. The liana cutting became an established silvicultural practice especially to free the trees in forest plantations.

Lianas have certain crucial ecological role in forest ecosystems. Tree fall in the tropical forest, forming a canopy gap, allowing sunlight onto the floor, is an occasion of immense activity on the exposed ground, where the falling light stimulates a flush of fresh growth in the vegetation. Tree saplings that have been almost dormant for years get activated, gaining height rapidly. The juvenile lianas with greater vigour, overtop these saplings creating virtually a sub-canopy in the tree fall gap. This canopy rises in the air pushed up collectively by the force of numerous juvenile trees, especially short duration pioneers, activated by sunlight. Once again a damp and dark interior is created underneath the canopy of lianas and pioneer trees (light-loving, fast growing, short lived trees like *Macaranga*, *Trema*, *Ervatamia* etc.). As the 'canopy lifting' happens, the characteristic species of the rain forest or evergreen forest find suitable microclimatic conditions driving the succession process towards the climax vegetation. The lianas help to stabilise the microclimate of the forest floor by forming a mass of leafy vegetation to close canopy gaps (Schnitzer and Bongers, 2002; Parthasarthy et al., 2004). Heavy load of lianas on trees, however, can cause mechanical damage of the hosts and also reduce their growth rates (Pérez-Salicrup, 2001). Addo-Fordjour et al., (2013) found liana species richness and abundance were significantly lower in the high disturbance forest, whereas the liana biomass was higher in low disturbance forests.

Lianas are woody stem rooted in the ground and need physical support for their growth due to weak stem. Liana competes with tree for resources such as soil nutrients, sunlight and water. Liana are prominent component of tropical forest which plays a vital role in ecosystem processes (foliage, fruit production and carbon sequestration) and species diversity. Species diversity of lianas encompasses of 25% and woody stem density accounts 10-45% mainly in tropical forests around the world. Western Ghats has higher species richness compared to Eastern Ghats and Coromandel Coast in Indian Peninsular. (Schnitzer et al., 2015, 2002, Parthasarathy et al., 2004, Muthumperumal and Parathasarathy 2010). Liana plays vital role in forest by maintaining diversity, regeneration, forest functioning includes nutrient cycling, forest transpiration, water use and carbon sequestration. Some of the liana species constitute group of non-timber forest product. Some species of Liana species has medicinal value. For instance, *E. rheedii* bark is used to cure scabies in Tanzania (Brink and Achigan-Dako, 2012). Liana also has wide range of benefits to arthropods, birds, arboreal mammals, primates by providing food resource (leaves, fruit, flowers, nectar, sap), exposure to a reduced suite of predators and also serve as fallback food i.e., abundant foods of relatively low quality that are used during periods of low overall food availability (Schnitzer et al., 2015). Seeds of *Entada rheedei* are cooked and eaten by especially forest dwelling communities. Entada is a promising candidate herb for the development of a phytomedicine against liver ailments (Gupta et al., 2011).

Liana grown successfully in a premier research campus is a breakthrough as opportunities have been opened up for various types of research – such as biomechanical characteristics of its specific parts, tropic responses, host preference, climbing mechanism, nitrogen fixation, type of photosynthesis (C3 or C4), root pressure, reproductive biology, mechanism in invasive growth and morphological response upon contact with support trees.

3. *Entada rheedei* (Fabaceae), the lianous species, is a conspicuous liana in the Western Ghats. It has a wider distribution in the world tropical Africa, India to China, Philippines and northern Australia. In India it occurs from sub-Himalayan tracts through the states of Sikkim and Assam to Bihar and Orissa to the monsoon forests of Western and Eastern Ghats (Brink, and Achigan-Dako, 2012). It is also found in the Andaman Islands. This magnificent liana is seen along river and stream sides of humid forests. *Entada rheedei* with its angled woody stems racing up even the tallest trees, coiling anti-clockwise and clockwise on support, is a phenomenal species that one could witness in the Western Ghats. Its growth dynamics could be now noticed in the urban ecosystem of Bangalore, by observing a remarkable specimen of *Entada*, in the Indian Institute of Science, on Silver Oak marg in front of the Centre for Ecological Sciences, introduced from the Western Ghats in late 1980's. Seeds of *Entada* were collected from the Western Ghats (13°55′–15°31′N, 74°9′– 75°10′E) about 55 km from the Arabian Sea, at an elevation of 700–800 msl. The region receives 450 cm or more annual rainfall, and during post-monsoon period the wind speed is 8–10 m/s. Following mechanical cracking of the hard testa, the seeds were kept in a coarse cloth bag and floated in pond water for about 20 days before sowing at various places in the campus. Of the seven seeds sown, one buried in the soil close to a tree of *Bauhinia purpurea* (Fabaceae) has grown into a liana, spreading its canopy on a miniforest of the semi-evergreen tropical trees.

A single plant has unexpectedly attained a gigantic size in 25 years, with its canopy infesting the crowns of nearby trees which covers an area roughly equivalent to 1.6 ha. It has remarkable aerial stolons, of about 15 m long, even crossing over a tar road through the air, without any support, and reaching the trees in a mini-forest on the other side where it is firmly anchored to trees and clumps of bamboos, spreading rapidly (Maheshwari et al., 2009). Frightened with the profuse growth and spread of aerial stolons (with the excuse of possible threat to motorists on the road below) one of the administrator got some stolons cut or pruned. It was noticed water trickled out of stolons, showing how an efficient water conducting system is working through the entanglement of branches.

Different parts of *Entada rheedei* have been used in native medicine. The folk healers of Araku Valley in the Vishakapatanam district apply seed paste to scabies and boils (Padal and Sathyavathi, 2013). Two new tryptophan derivative compounds from the seed kernels of *E. rheedei* may offer an alternative as potential therapeutic for cancer and AIDS (Nzowa et al., 2013). In Southeast Asian countries and in India the various parts of the climber are used in different ways to cleanse fresh wounds, heal minor scrapes and burns (Bureau of Plant Industry, 2009). Seed paste of Entada is applied over the affected and the inflamed swellings by the Kanikkar tribe of Agasthyamalai in Kerala, reduce pain due to rheumatism. Its anti-inflammatory property has been proved by Kalpanadevi et al., (2012).

The seeds of Entada from India are coveted items in the Egyptian market because of the medicinal values. Seeds of Entada are rich in potassium (K) and phosphorous (P) (1264 and 1240 mg/100 g respectively), followed by calcium (Ca) and sodium (Na) (199 and 68 mg/100 g respectively). The micro element Iron (Fe) level in the seed was 3.3 mg/100 g. Richness of these elements in the seeds probably accounts for their medicinal as well as dietary values (Okba et al., 2013). Amino acids are also an important constituent in seeds of *Entada rheedei*. According to the study of Okba et al., 2013 the total percentage of the amino acids in 100 grams of seeds was 23.499 g. Leucine is one of the essential amino acid (2.597 g/100 g seeds), followed by phenylalanine (2.116 g/100 g seeds) and lysine (1.776 g/100 g seeds). Phenyl alanine is useful in treating painful arthritic problems. Its relatively high level in Entada seed may explain its use in folk medicine specially for treating arthritis and other rheumatoid diseases. Glutamic acid (3.737 g/100 g seeds) was the main non-essential amino acid, which is important in the metabolism of sugars and fats and used in treatment of ulcers.

The *Entada* is encompassed of a mix of tree structures and a woody climber, and some unique structures. Its erect trunk is comprised of anticlockwise-twisted pleats. Its climber part comprises of hammock-like, twisted, woody stems. The structure that has spread its canopy from one support tree to another are long, leafless, cable-like stems (stolons) that navigated aerially approximately 15 m above the ground, differentiating foliage upon accessing a living tree.

3.1 Anticlockwise twists in climbing parts: The uncoiled trunk pleats have branched out into hammock-like, highly twisted, woody branches (Figure 1). Yet, no above-ground part has twined around a support tree or its branches, hence *Entada* is not a twiner. Rather, its branches mostly lie on the host branches for support and are occasionally entangled into them. A striking feature of *Entada* are the climbing branches shaped into an 'Archimedes screw' with pronounced tangential thickening (Figure 2) (Vogel 2007).

The predominantly anticlockwise helices in *Entada* prompted to examine the direction of coiling in climbers growing in a nearby miniforest in the campus. Anticlockwise ascend was observed in all climbers. Edwards et al in 2007 reported anticlockwise twining in plants at 17 sites in nine countries in both the northern and southern hemisphere. An exception is the yam *Dioscorea*, where species have been classified on the basis of stems twining to the left or to the right (Gamble 1935; Punekar and Lakshminarasimhan, 2002). The handedness of growth depends on the orientation in which cortical microfibrils are organized under the control of spiral gene (Hashimoto 2002). However, it is not known whether helical microtubule arrays are the cause or the consequence of organ twisting. We have not observed any thorns, hooks, spines or stem tendrils that could facilitate anchoring of *Entada* to the supporting tree. Rather, physical support is gained by occasional placing of its branches on those of support trees. Some of its overhanging leafy branches that were exposed to full sunlight during March–April (before monsoon rains begin) produced inflorescence (Figure 1.b).

3.2 Hydraulic supply: The parent and interconnected daughter canopies of *Entada* are founded on; a single germinated seed and hence on a single root system. Since the aerial stolons ultimately connect to the rooted trunk, these must constitute the hydraulic system for the entire canopy. When aerial stolons (cables) extending across a road junction, posing hazard to motorists were cut, colourless, watery sap trickled from the cut cables. This suggests that water is translocated by root pressure, requiring development of non-destructive methods for investigation of its underground parts. Apparently, the twists in plant structure do not resist the movement of water, making *Entada* a good material for investigations of pressure-generating capability for water movement, compared to a tree. Following severing, the daughter canopies differentiated by aerial stolons and distributed on surrounding trees dried, confirming that the aerial cables constitute the hydraulic supply system and the structural form for the spread of the canopy on support trees.

3.3 Ecophysiology: Occasionally, a terminal leaflet in the pinnate compound leaves of *Entada* is modified into a forked tendril. Tendril development may be influenced by the amount of light filtering through the canopy, and its function may only be to orient the leaf for maximal absorption of sunlight by the canopy in natural habitat under cloudy conditions. A visual comparison of the density of *Entada* foliage with that of the surrounding trees suggests that this liana invests more of photo synthetically fixed carbon in woody branches, which have a capacity to resprout after breakage.

The first sighting of a single 12 inches long, green pod was in May 2003, and again in 2005 2008, 2011 and 2015. It therefore appears that fruiting in the alien environment is a rare phenomenon, for unknown reasons. Although being a leguminous plant, *Entada* is assumed to be self-pollinated, the lack of a pollinator species could account for its rare fruiting. Further observations are required to determine if flowering and fruiting in the daughter canopies is synchronized with that of the interconnected parent canopy.

The ability to produce large pods with rather large seeds (Brandis 1921, Saldanha and Nicolson 1976) suggests a high photosynthetic rate. It is believed that lianas have a fast growth rate because of their high photosynthetic rate due to elevated CO_2 in the canopy (Granados and Korner 2002). Contrary to popular belief, liana density and growth are unrelated to the mean annual precipitation (Rowe 2004, Granados and Korner 2002, Schnitzer 2005). Schnitzer in 2005 reported that lianas grow nearly twice as much as trees during the wet season, but more than seven times that of trees during the dry season. This observation was corroborated by Swaine and Grace (2007). In view of the requirement of seedling material for experimental investigations in the laboratory, the reproductive biology of *Entada* assumes special importance.

3.4 Spreading strategy: Previously all reported lianas spread their canopy by means of ground stolons which then climb on available support. *Entada* is unique: it has formed specialized, cable-like, aerial stolons that have extended near-horizontally into air, crossing gaps and spreading canopy from the primary support tree onto the crowns of other support trees. The length of these aerial stolons exceeds 15 m; and there is no evidence of a support tree being present between the inter-support distances, because of a dividing tarred road. The aerial stolons traversing a road junction over a lamp post highlights of an unusual plant type growing in the campus. Following contact with the crown of support trees, the stolons have branched and much of their twisted woody branches appear to support each other (self-support), with this being augmented by the branches that have infiltrated into the trees. A stand of bamboo culms accessed across a gap due to a road is bent down to a greater degree than the uninfested culms, either because of the weight of *Entada* or because *Entada* exerted a force to pull them down. Structural adjustments that are required to counter stress and strain as a consequence of tension due to pull need further investigations. The aerial stolons are oriented towards a vegetated tract across a tarred road without crisscrossing, a possibility is that other than phototropism, some volatile chemicals produced by the 'host' trees not only provided a cue for the development of cables, but also directed their extension towards trellises.

This speculation is supported by a recent finding that volatile compounds, α-pinene, β-myrcene, 2-carene, p-cymene, β-phellandrene, limonene, (E,E)-4,8,12-trimethyl-1,3,7,11-tridecatetraene and an unidentified monoterpene released by tomato plant guide the dodder vine, *Cuscuta pentagona* (Runyon et al., 2007). Rowe and Speck (2005) have illustrated 'searcher branches' in a woody liana *Strychnos* sp. (Loganiaceae), having a cable-like appearance and extending horizontally 3–4 m across the canopy gap to locate new support. Upon contact with a neighbouring tree, the *Entada* cables (stolons) differentiated normal foliage, viz. compound leaves with thick leaflets. The branches of *Entada* have infiltrated and entangled with that of *Bauhinia purpurea*, *Cassia spectabilis*, *Broussonetia papyrifera*, *Tebebuia rosea*, *Eucalyptus tereticornis*, *Tectona grandis* and *Bambusa* sp. However, *Entada* was not observed on dead branches of standing trees, raising the possibility of requirement of living support trees for infestation. Since coiling, bending or flexing and differentiating into morphologically distinct parts occur in response to contact, the phenomenon of thigmomorphogenesis appears to be important in the infiltration and spread of *Entada* on living trees. It was not observed surface-growing stems in adult *Entada*. Its aerial stolons changed morphology upon accessing a support tree, suggesting that in addition to light and circumnavigational movement, contact-induced differentiation of foliage is important in mechanistic explanation of *Entada* spread on crowns of support trees as a straggler. Trellis availability is a major factor determining the success of canopy-bound lianas (Putz 1724).

3.5 Regeneration: Aerial stolons (diameter approximately <10 cm) that had begun to cause obstruction to vehicular traffic were cut. Two to four meter long cut pieces of woody stems (diameter 20–30 cm) were gathered and left in the open. In about 4 weeks the cut stems sprouted one to 1½ m tall shoots with stiff, erect stems producing foliage. Since sprouting occurred during the dry season, this observation signifies that *Entada* stores considerable water inside the stem tissue. However, the cut stems did not root, and the sprouts dried after the rains ceased. However, the ability of cut stems to re-sprout has implication in its natural habitat where strong wind and rain prevail: The branches that are unable to resist wind-induced breakage or those that are unstable under their own weight may fall on the ground and function as ramets (vegetatively produced, independent plants). This raises the question of the specific contribution of the ramets (broken and fallen branches that resprout and form roots) versus the genets (single individual plants from sexually formed seeds) in the composition of *Entada* thickets in its natural habitat.

3.6 Paradox of growth in alien environment: Factors that may explain an alien liana thriving in a place which receives only about 95 cm annual rainfall and where the soil surface (red earth) is generally dry, except for the monsoon months (May–September) are:

- Foremost, a safe mode of infiltration on available support trees by means of aerially formed stolons, thereby avoiding risk of injury from trampling by grazing animals.

- Nutrient-rich soil in the campus compared to the soils in rainforests is generally nutrient-poor because of the leaching of nutrients by rains through the millennia (Richards 1972, Terborgh 1992; Van der Heijden and Phillips, 2008).
- Presumed deep root system of *Entada* allowing access to water table, or water which seeped down from a nearby stream. This is in keeping with a report (Restom and Nepstad 2004) that root systems in excavated liana seedlings of *Davilla kunthii* (Dilleniaceae) in eastern Amazonia were more than eight times longer than the aboveground stem.
- Higher solar illumination (Heijden et al., 2008).
- Absence of herbivores or pathogens and less competition for resources as more area is available for aerial spread, root growth and nutrient absorption, unlike in dense vegetated tropical forests.

Despite the extensive spread of *Entada* genet in an alien environment. However, ecologically 'success' is a measure of reproductive efficiency, namely the number of individual genets or ramets per unit area and density of liana growth (Heijden et al., 2008). Success of introduced *Entada* be assessed by production of new genets or ramets.

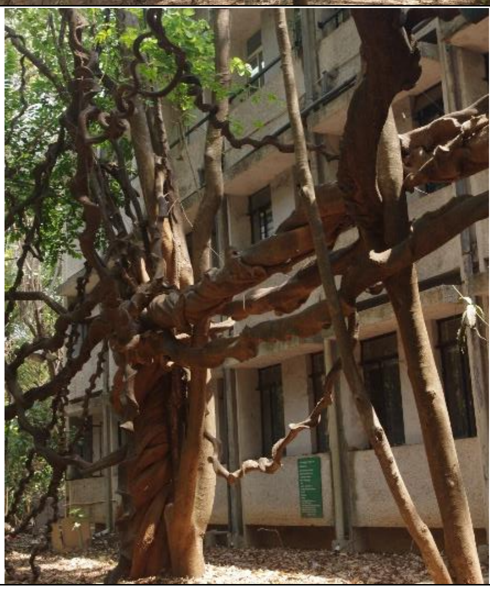


Figure 2: Hammock-like branches with twists. b. Spread of *E. pursaetha* c. The climber-form of *E. pursaetha* d. tree-form of *Entada pursaetha* self-supporting trunk in proximity to *Bauhinia purpurea*.

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