CHAPTER - I

1.1 Research Background

Climbing plants are one of the interesting growth forms in the plant world. They are non-self-supporting members from unrelated lineages and depend on some object or host to climb on external support to avail mechanical support for vertical growth towards the light (Putz & Mooney, 1991; Rowe & Speck, 1996; Isnard & Rowe, 2008; Cabanillas & Hurrell, 2012; Angyalossy *et al*., 2015; Sperotto *et al.*, 2020; Souza-Baena *et al.*, 2018; Leme *et al.,* 2021). They may be herbaceous and annual or woody perennial representatives occurring in 131 families of angiosperms (Gentry, 1991). Herbaceous climbers are also called vines and are with weak stems. Herbaceous climbers may be climbing, trailing, twining, or creeping along with the supporting surface (Liang *et al.,* 2010) and mostly they are annuals. In contrast, woody climbers (also called lianas) are perennial, woody, and reliant on on other objects (plants/any structure) to climb or entwine for mechanical support (Putz, 1984; Putz & Holbrook, 1991; Liang *et al.*, 2010). Furthermore, they have woody stems, survive for quite a few years, and use trees or other resources to support perpendicular growth and climb up to the canopy to get the sunlight. They are said to be evolved several times over a long evolutionary history of vascular plants (Gentry, 1991; Rowe *et al.*, 2006; Burnham, 2009; Field *et al.*, 2012; Pace & Angyalossy, 2013; Angyalossy *et al.*, 2015). They increase their stem thickness by various means by developing the cambial variant (Carlquist 1988, 2001) like regular vascular cambium, by forming successive cambia, interxylary phloem, by forming phloem wedges, compound or polystelic condition and fissured stems (Metcalfe & Chalk 1950, 1983; Obaton, 1960; Putz *et al.*, 1991; Isnard *et al.,* 2009; Angyalossy *et al.*, 2015; Schnitzer *et al.*, 2015). Lianas are a noticeable component of tropical forests and are considered as one of the most important members of species diversity and show significant differences in compositional between tropical and temperate forests (Gentry, 1991; Campbell & Newbery, 1993; Schnitzer & Bongers, 2002; Perez-Salicrup & Meijere, 2005).

All the non-self-supporting plants have slender and narrow stems as compared to the given leaf area they possess (Field *et al.*, 2012). This reduction in stem diameter is due to the reduced investment of energy in wood deposition and the use of saved energy towards the extension growth than radial one. Their thin and narrow stems provide them with an opportunity to utilize the free space on or around the standing or self-supporting host trees and their weight is shared by the host (Field *et al.*, 2012). They entwine/climb around the support and once the support is available, they undergo fast alteration in morphology as well as internal stem structures that facilitate them to climb vertically by developing tendrils, spines, hooks and adventitious adhesive structures (Darwin, 1867; Gentry, 1991; Putz 1984; Putz & Holbrook, 1991; Isnard & Silk, 2009; Leme *et al.*, 2021).

In the last two decades, climbing plants have attracted the attention of ecologists due to their crucial role in the forest ecosystem especially related to carbon sequestration (Isnard & Silk, 2009; Schnitzer & Bongers, 2011). Though, Darwin (1867) elaborated on the evolution of the climbing habit and modification of aerial organs for climbing purposes. This group of plants was much neglected in the 19th century due to their relatively less economic significance as compared to timber trees (Carlquist, 1996; Rajput *et al.*, 2017). Climbing plants attracted the attention of several researchers only after the publication of a seminal article by Darwin (1867) on climbers. He elaborated on the evolution of this group and provided detailed information on morphological and anatomical modification towards the climbing habit.

Tropical regions encompass the vast diversity, abundance, and taxonomic composition of climbing plants (Richards, 1996). They constitute considerable portion of the plant diversity in most of the tropical forest ecosystems around the world, which includes countries like Africa, South America, Asia, and the low land tropical forests (Gentry, 1991; Schnitzer & Bonger, 2002; Parren, 2002). This group of plants occupies nearly 44% of woody plant biomass in the Amazon basin (Perez-Selicrup *et al.*, 2001) while nearly 25% of woody climbers in Malaysia (Acevedo-Rodrigues, 2005). As compared to plain areas, their occurrence and distribution are more

established in the successional parts of the secondary forest (Balee & Campbell, 1989). Besides the rainforests, the dry tropical and moist forest also represents the quite healthy distribution of climbing habits while temperate zones represent the poor distribution of the lianescent habit (Gentry, 1985). However, available information indicates that the temperate forest of southern regions of Chile is having relatively higher diversity of climbing species (Dawson, 1993). According to Putz (1984), the lianas have been expected for 32-36% of the litter composition of the various forests.

Though climbers are the most important component of the forest ecosystem and as a supreme significant physiognomic feature of tropical forests (Croat, 1978), the most economic judgments of tropical forests are towards the timber products from trees because forest also provides non-timber goods that are used by millions of individuals all over the globe (Putz & Windsor, 1987; Tra Bi, 1997; Tra Bi *et al.*, 2002; Patel, 2013). Perry (1978) and Oliever-Bever (1986) reported that over thousand different climbing species belonging to 52 families have lots of economic importance. Like trees, climbing plants also have extraordinary significance in many aspects of forest diversity, and they play an important role in forest regeneration and dynamics (Schnitzer & Bonger, 2002). All the parts of climbing plants *viz.* root, tuber, stem, leaves, flower, fruits and seeds have useful applications.

Lianas flourish in gaps in the canopy and on the top of the host and surrounding trees. This feature of lianas creates competition in trees for growth and development (Tabanez & Viana, 2000). In a dry season, lianas in tropical forests are contributing a major part of the transpiration as compared to the trees (Meinzer *et al.*, 1999) and plays a remarkable role in forest carbon sequestration (Schnitzer & Bongers, 2011). Though, they have an important role in carbon sequestration, large and woody climbing species reduce tree regeneration, which consequently leads to a reduction in the quantity of carbon sequestered in the vegetal biomass (Chave *et al.*, 2001).

Besides this ecological significance, climbing species also play an important role in human welfare and some of them are listed as follows:

As a food: Several lianas act as an essential part of the diet for several wild animals particularly when there are no flowers and fruits in those plants that are routinely used by them (Putz & Windsor, 1987). They also provide valuable habitat and networks among tree canopies which empower the arboreal animals to pass through the tree tops from one tree to another (Schnitzer & Carson, 2001). They are a good source of food for human being by providing stems, tubers, leaves, flowers, fruits, and seeds, which can be used raw or cooked or in the preparation of pickles (Patel, 2013). Species of *Dioscorea* and *Ipomoea batata* are well-known examples which provide tubers that are used as food all over the world. Members of the Cucurbitaceae family are the major source of Gourds which are used to make Salads, Juices, and curies, and help to stay hydrated during summer days. Similarly, the family Fabaceae provides beans and pulses with high protein-rich food whereas the beetle nut vine of the family Piperaceae provides the valuable element in chewing beetle nuts (Putz & Mooney, 1991).

As a medicine: Climbing plants are used since long back in human civilization in various ways to cure ailments. Tra Bi (1997) and Tra Bi *et al.*, (2002) have studied the liana utilization by local tribes in forests of Scio and Haut Sassandra of the African country Cote d'Ivoire and described around 114 different species of lianas which are used for various purposes by the local population. Interestingly 83 species of lianas are used as medicine, 20 species as a portion food, 19 different species for traditional house constructions, 16 species are used for various hand-crafted works, 5 species of lianas are used as hunting tools, 9 species as a mouth and teen hygiene and 16 different species as an aphrodisiac drug. According to Tra Bi (1997), nearly 83 species of lianas are used in 197 pharmaceutical preparations for many diseases. A Cameroonian liana species *Ancistocladus korupensis* provide alkaloids with anti-HIV activity (Foster & Sork, 1997) which is an extremely important one. Patel (2013) reported 43 different climbing plants of 37 genera and 16 families are used for the ethnomedicinal purpose in Gujarat state, India. Among them, highly utilized plant families are Fabaceae, Apocynaceae, Cucurbitaceae, Convolvulaceae, Dioscoreaceae and Menispermaceae (Patel, 2013).

As an ornamental: The magnificence of any place like a garden, house, institute or even any house balcony can be heightened by growing the climbers. The stems of climbing plants are highly flexible; thus, they can be easily modified into various shapes as per the structure or shape to be given. Dynamic canopy, attractive stem shapes and beautiful flowers with fragrance give them a very high ornamental value and designate them a prominent position among all the plants used for their aesthetic value. Different climbers like *Allamanda cathartica, Argyreia nervosa, Bougainvillea spectabilis, Cissus quadrangularis, Clitoria ternatea,* and species of *Ipomoea* like *I. quamoclit, Jacquemontia paniculata, Merremia quinquefolia, Monstera deliciosa*, several species of *Passiflora*, *Quisqualis indica* and several more are the well-known examples that are cultivated as ornamental plants (Patel, 2013).

Role in the forest: Woody climbers/lianas also play a crucial role in the forest ecosystem in terms of diversity, regeneration and functioning of nutrient recycling, forest evapotranspiration and water use, and carbon sequestration (Schnitzer & Bongers, 2002). They are also responsible for the reduction in tree growth rates by competing for underground and above-ground resources (Schnitzer *et al.,* 2015; Schnitzer & Bongers, 2011; Chave *et al*., 2001; Tobin *et al.*, 2012) and directly or indirectly plays role in the reduction in their growth. They share their weight on supporting host trees which cause trees to bend whereas twisting of woody climbers around tree trunks constricts the stem and decreases their timber value but at the same time, this also prevents the trees from being cut out (Putz, 1984; Babweteera *et al*., 2000; Parren, & Bongers, 2001; Schnitzer & Carson, 2001). In the forest ecosystem, lianas not only help in vegetation regeneration but are part of the food web and food chain of several animals. They are also helpful in linking trees for stability and providing a road for arboreal animals and restricting vegetation development in logging gaps (Bongers *et al.*, 2002).

Lianas and animal association: Lianas are main part of the lowland forest ecosystem and provide many resources as mentioned above to several animal groups also (Gentry, 1991; Yanoviak & Schnitzer, 2013). It is believed that lianas are also responsible for the evolution in morphology and behaviour of several arboreal animals

(Benson *et al.,* 1975; Emmons & Gentry, 1983). Stein *et al.,* (2012) explained the coexistence between arthropods and climbing plants for millions of years due to their close ecological associations. Walter *et al.,* (1994) reported mite density is more than 10,600 m^2 on lianas as compared to self-supporting plants which is much higher than the tree species. In tropical forests, non-self-supporting plants have played an important role in the evolution and ecology of many insects and arboreal animals in terms of support, shelter, and food (Clarke & Kitching, 1995; Benson *et al.,* 1975; Emmons & Gentry, 1983; Stein *et al.,* 2012; Smiley, 1987; Trigo & Motta, 1990; Coley & Barone, 1996). Likewise, lianas and birds are also sharing relationships which benefit both i.e., birds get food as well as shelter while birds help them in seed dispersal. Many a time, lianas provide them site for nesting and foraging the birds, with no benefits no costs to the lianas. Certain insectivorous birds eat the insects on lianas and protect them from being punched by insects; some of the birds depend on fruits of lianas that help in their seed dispersal, pollinating birds depend on nectars and perform the act of pollination (Skutch, 1969, 1971; Stiles, 1981; Stein, 1992; LaFrankie, 2005; Gryj *et al*., 1990; Putz *et al*., 2001; Fleming *et al*., 2005; Kominami *et al*., 2003; Muller-Landau & Hardesty, 2005; Sankamethawee *et al*., 2011). The arrays of distribution of gliding and prehensile-tailed mammals concerning lianas are explained by Emmons and Gentry (1983). As per the explanations and critics (Emmons & Gentry, 1983; Jackson, 1999; Goldingay, 2000; Dudley *et al*., 2007), a close relationship between mammals and lianas may have played a major key role in the evolution of mammals. Their role in primate behaviour, biology, conservation, and ecology is also one of the important aspects of animal conservation. Primates also use lianas for food, shelter, locomotion, and as a fallback food during food scarcity (Arroyo-Rodríguez *et al.,* 2015; Dunn *et al.,* 2012; Kilgore *et al.,* 2010; Yanoviak, 2015; Lambert & Halsey, 2015).

Lianas represent one of the principal plant growth tactics, which are evolved over time scale (Rowe & Speck, 2005). The climbing habit has a long evolutionary history and is believed to be originated autonomously in the angiosperms, gymnosperms, and ferns (Isnad & Field, 2015). The origin of the climbing habit in a

certain group of plants also altered the ecology of plant groups, in specific the drift of and response to disruption in forests ecosystem and how it recycle the resource in ecosystems (van der Heijden *et al.*, 2015). Though they are important components of forest ecosystems, studies on various aspects of their existence are always neglected by earlier researchers (Schnitzer & Bongers, 2002, 2011; Wyka *et al.*, 2013; Schnitzer *et al.*, 2015). However, in the last two to three decades, several researchers have proposed that lianas are essential operators in tropical forests and have an important contribution to the function and dynamics of the forest ecosystem (Schnitzer *et al.*, 2015).

The geographical distributional pattern of lianas is defined by the latitude and they are more abundant in the tropical regions, while they are less distributed in the higher latitudes, either in the northern or southern hemispheres (Gentry, 1991; Schnitzer, 2005; Jiménez- Castillo *et al.*, 2007). There are few species of climbing plants (particularly liana) that are adjusted to temperate climates and their diversity declines gradually as moving away from the Equator zone (Gentry, 1991; Schnitzer, 2005; Jiménez- Castillo *et al.*, 2007) and they are enormously abundant and varied in tropical forest gaps (Gentry, 1991).

Throughout the process of evolution from self-supporting towards non-self-supporting growth form, plants have not only transformed their internal structure of conducting elements but also revised the external morphology that helps them to climb or entwine around the supporting object or host (Rowe *et al.*,, 2004; Isnard & Silk, 2009). Darwin (1865) for the first time categorized climbing plants into five categories based on their mode of climbing mechanism and modification of aerial organs which work as the specialized structures playing a strategic role in their climbing behaviour as twiner (e.g., *Ipomoea*, *Merremia*, *Convolvulus*, *Cocculus hirsutus*); Leaf climbers (*Clematis gauriana*, *Gloriosa superba*, *Smilax zeylanica*) Tendril climbers (*Passiflora*, *Cucurbits*, *Serjania*); Root climbers (*Vitis*, *Epipremnum aureum* [money plant], *Ficus pumila*); Hook climbers (*Artabotrys odoratism*, *Ancistrocladus benomensis*, *Calamus*) (*cf*. Isnard & Silk, 2009).

i) Twining plants: The plants that twine around the host and form a helical cylinder of vascular tissues around the support. Such twisting usually takes place below 2-3 internodes (Isnard *et al.*, 2009). Darwin (1865) referred to this phenomenon as circumnutating members. The angle of twisting of a climber depends on the surface of the supporting object, which increases with the increase in roughness of the supporting surface (Darwin, 1865; *cf.* Isnard *et al.*, 2009). The twinning of plants may be clockwise or anti-clockwise direction, which is under debate for several years. Examples of twiner include *Argyreia, Dioscorea, Jaquemontia, Ipomoea, Operculina,* etc.

ii) Leaf climbers: A group of plants in which the portion of the leaf (i.e., petiole, rachis, leaf apex etc.) is modified into various specialized structures for climbing purposes around the supporting host; for example, *Bauhinia, Clematis, Gloriosa* etc. As per Darwin (1865), such plants have sensitive organs (referred to as irritable organs) that clasp around the supporting host after forming the contact. Such sensitive or irritable organs twine around the host more rapidly than the twining plants. In this category, Isnard and Silk (2009) also included hooks which resemble leaves but ontogenetically they may be branches, petioles, rachis, peduncles or stipules (e.g., *Artabotrys, Clematis, Smilax, Strychnos, Uncaria*, etc.).

iii) Tendril climbers: Tendrils are long, slender, filiform, or thin wire-like irritable organs, which are a specialized modification of stem, leaf, flower peduncle (Isnard & Silk, 2009) or petiole that help the plant to climb vertically by binding around the supporting host or by sticking to as mentioned above. Tendrils may be a few centimetres in length and may reach up to 40 cm in length as in the case of *Vitis vinifera* (Jaffe & Galston, 1968). Examples: Species of *Vitis, Passiflora, Cucurbita, Luffa*, etc.

iv) Root climbers**:** Some of the climbing plants develop aerial roots that play an important role in climbing around the support by producing specialized sticky pad-like organs (Hegarty, 1991; Isnard & Silk, 2009; Melzer *et al.*, 2010, 2012; Bohn *et al.*, 2015), which attach along the bark or walls of the constructions. They are similar

to coiling and adhesive tendrils; root climbers can be categorisedas adventitious roots that wind around the host or they may stick on flat surfaces including stem trunks or walls. Examples: *Aralia, Ficus pumila, F. repense, Hedera helix, Parthenocissus tricuspidata, Pothos* etc.

v) Hook climbers: These include the plants that climb with the help of re-curved spines, hooks or thorns. Usually, this feature is more common in straggling shrubs like *Artabotrys hexapetala, Desmoncus* (climbing palm), and *Uncaria ovalifolia* etc., depending on the situation, the hooks may undergo secondary thickening and develop a significant amount of secondary xylem which may support up to 25 kg weight as in case of *Desmocus* (Isnard & Rowe, 2008). Similar thick hooks are also observed in *Artabotrys*.

Gentry (1985) classified the climbing plants into four fundamental strategies based on their morphology and ecology. **I) Lianas**: Woody and comparatively thick-stemmed climbers. They begin their life as terrestrial plantlets and are adept to develop in mature forests. **II) Vines**: The climbers with narrow stems that initiate life as terrestrial seedlings and grow in the forest edge. **III) Woody hemi-epiphytes**: The stranglers characteristically start life as epiphytes with roots which later reaching to the grounds. **IV) Herbaceous epiphytes**: This group of plants involve all the herbaceous species that ascent in association with tree trunks, twigs and branches.

Hegarty and Caballe (1991) categorized lianas into active and passive types based on the climbing mechanisms. Passive climbers are scramblers and lianas climbing with the help of thorns, may not be able to climb to reach up to the canopy level as chances of falling off. Active climbers are those who use roots, hooks, tendrils and twiners as a climbing mechanism and are also able to reach up to the high (Nabe-Nielsen, 2001).

Besides these, several other researchers also have made efforts to define the non-self-supporting plats e.g., Schenck (1992, 1993); Hegarty (1991); Acevedo-Rodríguez (2003, 2005); Isnard & Silk (2009); Vaughn & Bowling (2011); Villagra &

Neto (2014). In Flora of Brazil (2020), authors categorized climbing plants into three main categories "Liana/Twiner/Climber". As per these categories, lianas are woody plants; twiners are the plants which twins around the host to climb and the term climbers are used in general for the climbing plants irrespective of their climbing mechanism or woodiness.

Sperotto *et al.*, (2020) classified climbing mechanisms into; i) simple scrambling plants that climb over the host without any specialized structure or active mechanism. Beentje (2010) referred to it as Rambling plants. ii) Hooks or Grapnels are those climbers which are having hooks or grapnels, a specialized structure in some climbing palms *Desmoncus*, *Uncaria* (Isnard & Rowe, 2008; Treub, 1883). iii) Adhesive roots are characterized by the presence of adhesive adventitious roots that secrete sticky substance and helps them to stick on walls or host, e.g., *Adelobotrys* (Melastomataceae), *Passiflora* (Passifloraceae), *Piper* (Piperaceae), *Vanilla* (Orchidaceae), *Marcgravia* (Marcgraviaceae) and *Philodendron* from Araceae (Sperotto, 2020). iv) Active climbers are plants showing the support searching behaviour for twining; a rhythmic growth movement of stem shoots (Darwin, 1865; Hegarty, 1991; Carlquist, 1991; Putz *et al.*, 1991; Isnard & Silk, 2009). V) Twiners are the plants that coil their stem around the supporting host e.g., members of Menispermaceae, Apocynaceae, Aristolochiaceae, Malpighiaceae and some Gymnosperm (Darwin, 1865; Schenck, 1893; Obaton, 1957, 1960; Gentry, 1991; Burnham & Revilla-Minaya, 2011). The direction of climbing from left to right (i.e. Dexto-rotatory) and from right to left (i.e. Levorotatory), is a very specific and phylogenetically correlated (Hegarty, 1991; Edwards *et al.*, 2007; Burnham & Revilla-Minaya, 2011) phenomenon and it is reported in several members. vi) Prehensile branches, they are the twining plants that do not use their main stem for twining, instead, use lateral branches to twine around the host support (Putz, 1984; Hegarty, 1991; Burnham & Revilla-Minaya, 2011). Prehensile branches are equal to the tendrils (Hegarty, 1991) but there is no structural modification in it (Acevedo-Rodríguez, 2005). Examples of such members are *Securidaca* (Polygalaceae), *Connarus* (Connaraceae), *Peritassa* and *Hippocratea* (Celastraceae) and different

climbing species of *Machaerium* from the family Fabaceae (Sperotto, 2020). vii) Tendril is a thread-like organ-modified stem or leaf exclusively used for ascending purposes (Darwin, 1865; Font-Quer, 2001; Sousa-Baena *et al.*, 2018a). Morphologically and ontogenically variable and it also provides the best example of convergent evolution (Sousa-Baena *et al.*, 2018b). The shape of tendrils varies from simple-ended, branched, circinate, spring-like coiling or without any specific shape (Sperotto, 2020). viii) Twining petioles (or prehensile leaves) are the plants which use the petiole as a twining organ for support (Darwin, 1865; Hegarty, 1991; Acevedo-Rodríguez, 2005; Bell & Bryan, 2008; Durigon *et al.*, 2014, 2019). ix) Twining peduncles and inflorescences, the plants which use floral peduncles to twine around the support of very less common plants (Sousa-Baena *et al.*, 2018b).

Lianas represent nearly 20-25% of total aboveground biomass (Gentry & Dodson, 1987, Schnitzer *et al.*, 2005), and contribute about 40% of leaf productivity in tropical forests (Hegarty & Caballé, 1991). Their increasing inhabitants in the tropical forest are interrelated with increasing forest instabilities, forest fragmentation and increased concentration of CO_2 in the atmosphere (Philips *et al.*, 2002, Schnizer & Bongers, 2011). This group shows a unique pattern of resource distribution, which is related to well-organized nutrient recycling to enhance the light-stimulated carbon uptake as well as growth response under high light circumstances (Gentry & Dodson, 1987, Schnitzer *et al.*, 2005, Philips *et al.*, 2002, Schnizer & Bongers, 2011). Therefore, to comprehend the functional ecology of lianas is crucial and is of critical significance in calculating the destiny of tropical forests during this period of climate change.

Despite of all these importance, various aspects of their growth and development, their role in the forest ecosystem was neglected by earlier researchers. However, in the last two decades, this group of plants fascinated the attention of several researchers to investigate various aspects of their life cycle including their ecology, evolution and structural alterations induced in response to the shift from self-supporting to climbing habit. The present study is just a small piece of such an attempt

to understand histological changes in their internal structure and the evolution of new growth trajectories to adjust to narrow stems versus the large canopy they possess.