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(RESEARCH ARTICLE)

MORPHOLOGICAL, ANATOMICAL, AND ADAPTIVE DIVERSITY OF CLIMBING PLANT SPECIES IN AZAGNY NATIONAL PARK, SOUTHERN CÔTE D'IVOIRE

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ABSTRACT

Climbing plants include woody lianas and herbaceous vines, as well as scrambling plants. They are important components of tropical forests. However, information on these plants, particularly their diversity, remains fragmented and insufficiently detailed. This study aimed to improve our understanding of the ecological diversity and biological characteristics of climbing plant communities in Côte d'Ivoire. A botanical inventory was conducted and stem samples were collected in Azagny National Park (ANP). The collected stems were sectioned, and their cross-sections were described according to established categories of tissue arrangement. Three main stem shapes were observed: cylindrical, flattened, and lobed. Species with cylindrical stems predominated, accounting for 86% of the species. Based on their anatomical structure, woody climbers in ANP could be divided into two main groups: those with a single woody cylinder and those with compound woody structures. A single circular woody cylinder was the most common structure and resembled the anatomy of self-supporting plants. Six climbing mechanisms were recorded. Climbers with touch-sensitive organs and stem twiners were the most species-rich groups, accounting for 31% and 30% of the species, respectively. Some climbing mechanisms were associated with particular botanical families. All recorded Convolvulaceae and Menispermaceae species were stem twiners, whereas the Cucurbitaceae, Vitaceae, and Passifloraceae species were tendril climbers.

Keywords: Climbing plants; Biological Diversity; Stem Anatomy; Azagny National Park; Côte d'Ivoire.

1 INTRODUCTION

Climbing plants rely on other plants for support to reach greater heights. They occur worldwide, particularly in tall vegetation, where climbing is advantageous or necessary [1, 2]. They are especially common in tropical rainforests, where they generally account for approximately 20 to 30% of the vascular plant flora. These plants also grow rapidly and have a strong capacity to resprout. Light is considered an important factor influencing their distribution and abundance [3, 4]. They occur in vegetation types worldwide, in both tropical and temperate climates [5, 6].

Climbing plants differ from trees in their architecture, growth form, development across forest strata, and the nature and shape of the supports to which they attach. Their growth forms range from small, inconspicuous climbers ascending tree trunks to giant lianas with tree-sized stems that appear to hang independently within the forest [7, 8, 9].

Climbing plants are abundant and exhibit diverse growth forms in almost all tropical forests [5]. As a functional group, they display the greatest anatomical diversity in the plant kingdom [10, 11] and have highly distinctive morphological and anatomical characteristics. One of their most conspicuous features is their considerable stem length relative to stem diameter. Their identification is difficult because vegetative and reproductive organs are often located high in the crowns of large trees and are therefore difficult to access. This limitation highlights the importance of developing alternative identification methods. Climbing plants are also widely used for food, traditional medicine, and handicrafts [12, 13], and products derived from their organs provide substantial income for many households in tropical regions.

Unfortunately, these valuable species, like other components of forest flora, are threatened by human pressures, including agricultural activities and large development projects [14]. Moreover, few studies have focused on climbing plants in Côte d'Ivoire in general, or in Azagny National Park in particular.

There is therefore a need to improve knowledge of the ecological diversity, biological characteristics, and morphological types of climbing plant communities in Côte d'Ivoire. Against this background, the overall objective of this study was to improve understanding of climbing plant diversity and establish a sound baseline dataset to support the development of strategies for biodiversity conservation and sustainable use. Specifically, the study aimed to (1) assess the morphological and anatomical diversity of climbing plant species and (2) examine the relationships between anatomical structures and climbing mechanisms.

2 MATERIALS AND METHODS

2.1 Study site

Azagny National Park is located in southern Côte d'Ivoire, between the administrative departments of Grand-Lahou and Jacqueville [15]. The park covers 21,850 ha and lies within the Upper Guinean phytogeographical region, which extends from Togo to Senegal [16]. Its vegetation forms a mosaic of contrasting vegetation types, ranging from grass savanna to dense forest and including secondary vegetation [17]. The park has gently undulating terrain. The regional climate is subequatorial, with two dry seasons and two rainy seasons. Mean annual rainfall is 1,650 mm, mean annual temperature is 26 °C, and mean relative humidity is approximately 85% [14].

2.2 Study materials

The study materials comprised biological samples and field equipment. Mature climbing plant stems were used to describe morphological types, while samples of young stems were collected for anatomical sectioning. Field equipment included a digital camera for photographic documentation, pruning shears for sample collection, and sandpaper for smoothing stem cross-sections.

2.3 Data collection

Data were collected through roving botanical surveys across the different habitats of Azagny National Park. For each climbing plant species, morphological type and climbing mechanism were determined by direct observation or with reference to [18, 19, 20].

Stem samples were collected, dried, cut transversely, and sanded for macroanatomical examination. Only sections meeting a minimum diameter threshold of 2–3 cm were retained. The features examined included cross-sectional outline, the arrangement of major tissues, and the configuration of the cambial layer, following the criteria in [21]. Morphological and macroanatomical observations were recorded on a standardized data sheet to facilitate comparisons among species.

2.4 Data analysis

2.4.1 Morphological diversity of climbing plants

Morphological diversity was assessed from the stem shapes observed in transverse section, namely cylindrical, flattened, and lobed forms. Following the comparative approach in [9], species were assigned to distinct morphological categories.

2.4.2 Stem macroanatomical structures

Stem macroanatomy was examined by classifying woody climbers into two main groups: those with a single woody cylinder and those with compound woody structures. These groups were further subdivided according to the arrangement of major tissue categories and the configuration of the cambial layer. The single-cylinder group included regular, radiating, and furrowed wood, whereas compound structures comprised wood in discrete masses, dispersed wood, and successive woody bands [21].

2.4.3 Adaptive diversity of climbing plants

Adaptive diversity was assessed using the six climbing mechanisms recorded in Azagny National Park: stem twining, touch-sensitive organs, tendrils, hooks, clinging roots, and scrambling. This classification followed the climbing strategies described in [18, 19, 20].

2.4.4 Relationships between anatomical structures and climbing mechanisms

Relationships between anatomical structures and climbing mechanisms were examined by comparing the frequencies and distribution of anatomical structures within each climbing category. This approach provided the number and proportion of anatomical structures associated with each mechanism and identified structures that were either exclusive to particular categories or shared among them. It followed the comparative approach used in [22, 23] to investigate relationships between stem anatomy and climbing mechanisms.

3 RESULTS

3.1 Morphological diversity of climbing plants

Three main stem shapes were observed in ANP (Figure 1). Some species had cylindrical stems, as exemplified by *Secamone afzelii* (Apocynaceae). Others had flattened stems, as in *Iodes liberica* (Icaciniaceae), or lobed stems, as in *Combretum racemosum* (Combretaceae). Species with cylindrical stems were the most common, accounting for 86% of the species recorded in ANP, followed by those with lobed stems (9%). Species with flattened stems were the least common, accounting for 5% (Figure 2).

Figure 1: Main stem shapes of climbing plants: cylindrical stem of *Secamone afzelii* (a); flattened stem of Iodes liberica (b); lobed stem of Combretum racemosum (c).

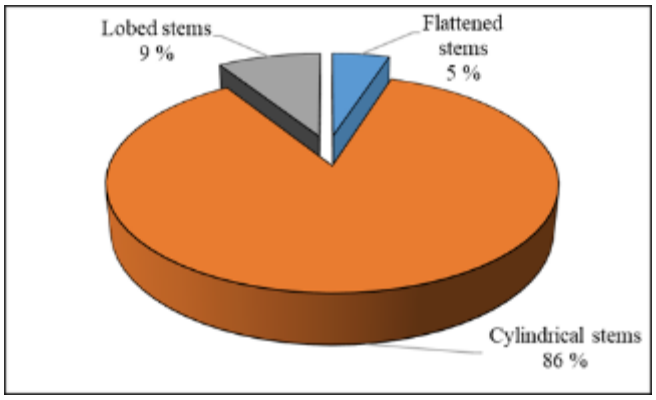

Figure 2: Distribution of stem shapes among the climbing plant species recorded in Azagny national park.

3.2 Stem macroanatomical structures

Field observations and published macroanatomical information provided data on 158 climbing plant species recorded in ANP. The samples examined displayed several macroanatomical structures. Stem cross-sections showed either a single, uniform stele, comprising a continuous woody cylinder, or a compound arrangement in which the wood occurred in separate portions. The stele is the central vascular region containing xylem and phloem.

Three macroanatomical structures were distinguished among climbers with a single woody cylinder: regular wood, radiating wood, and furrowed wood. Regular wood was exemplified by *Secamone afzelii* (Figure 3a), radiating wood by *Piper guineense* (Figure 3b), and furrowed wood by *Neuropeltis acuminata* (Figure 3c).

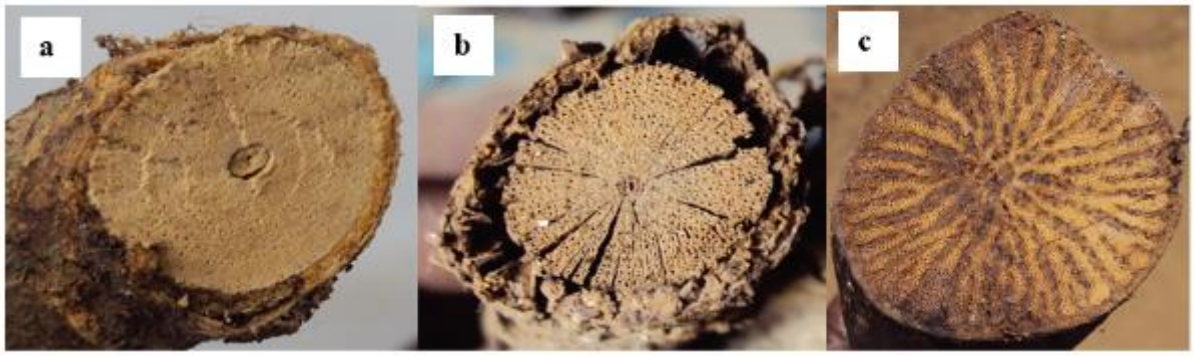

Figure 3: Stem cross-sections showing regular wood in *Secamone afzelii* (a), radiating wood in *Piper guineense* (b), and furrowed wood in *Neuropeltis acuminata* (c).

Climbers with compound woody structures exhibited greater anatomical diversity. Three categories were distinguished: wood in discrete masses, dispersed wood, and successive woody bands. Wood in discrete masses was exemplified by *Passiflora edulis* (Figure 4a), and dispersed wood by *Flabellaria* sp. (Figure 4b). In this study, successive woody bands comprised three subcategories: concentric rings (Figure 4c), partitioned concentric rings (Figure 4d), and successive bands with multidirectional growth (Figure 4e).

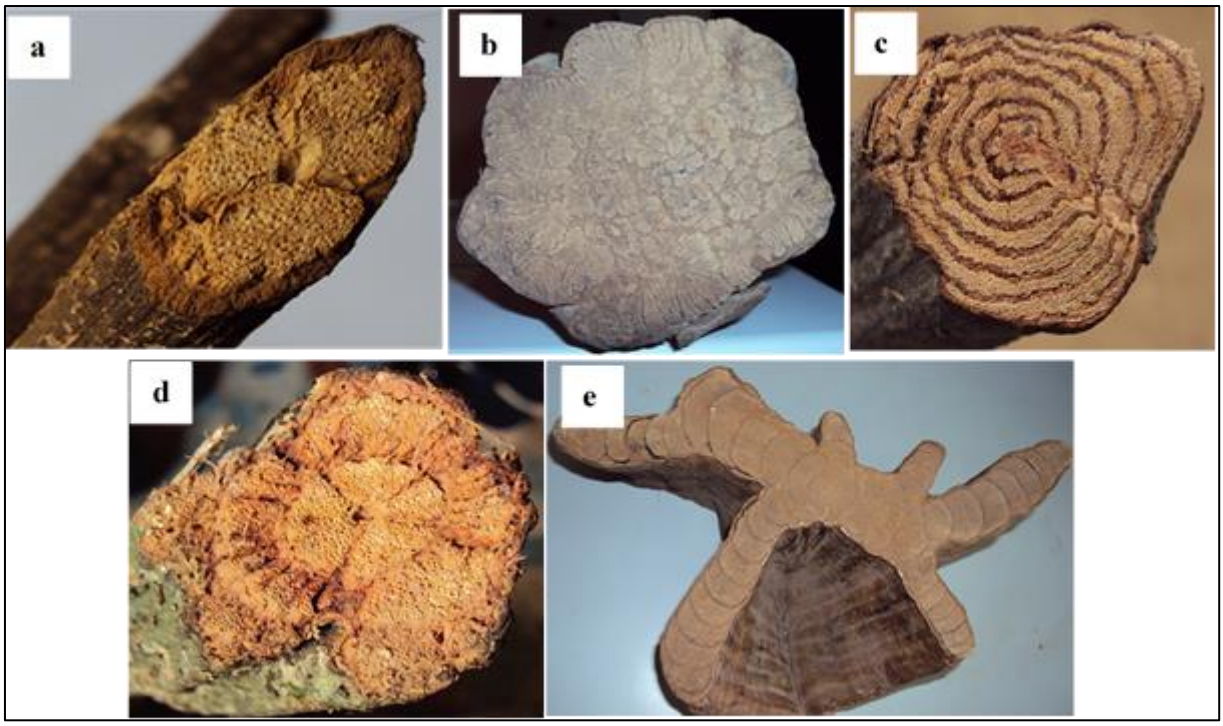

Figure 4: Stem cross-sections showing wood in discrete masses in *Passiflora edulis* (a); dispersed wood in *Flabellaria* sp. (b); concentric woody rings in *Salacia* sp. (c); partitioned concentric woody rings in *Adenia cissampeloides* (d); and successive woody bands with multidirectional growth in *Santaloides azelii* (e)

3.3 Adaptive diversity of climbing plants in ANP

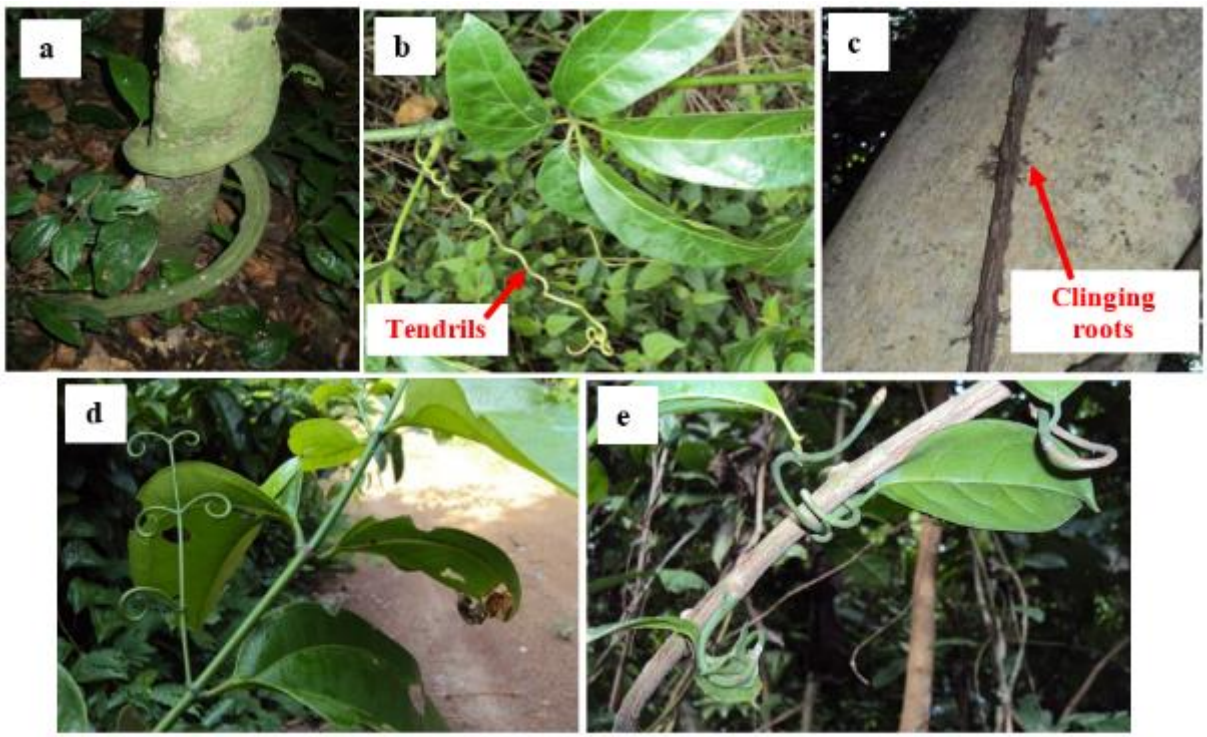

Figure 5: Twining stem of *Tiliacora dinklagei* around a support (a); leafy stem of *Cissus aralioides* bearing tendrils (b); stem of *Piper guineense* bearing clinging roots (c); leafy branch of *Strychnos aculeata* (Loganiaceae) bearing hooks (d); and touch-sensitive organs of *Salacia debilis* (e).

The climbing plant species recorded in ANP collectively exhibited six climbing mechanisms: stem twining, touch-sensitive organs, tendrils, hooks, clinging roots, and scrambling.

Figure 5a illustrates stem twining in *Tiliacora dinklagei*. Tendril climbing is illustrated by *Cissus aralioides* (Figure 5b), root climbing by *Piper guineense* (Figure 5c), hook climbing by *Strychnos aculeata* (Figure 5d), and climbing with touch-sensitive organs by *Salacia debilis* (Figure 5e).

The six climbing mechanisms were unevenly represented across the habitats surveyed in ANP. Climbers with touch-sensitive organs and stem twiners were the predominant groups (Figure 6), accounting for 31% and 30% of the species, respectively. Climbers with touch-sensitive organs occurred in several families, including Apocynaceae, Celastraceae, and Fabaceae. Some families, such as Convolvulaceae and Menispermaceae, comprised only stem-twining species. Hook climbing was the third most common mechanism (18.7%). Hook climbers belonged to families such as Rutaceae, Loganiaceae, and Arecaceae. Tendril climbers accounted for 11.4% of the climbing plant species. Species in Cucurbitaceae, Vitaceae, and Passifloraceae climbed exclusively using tendrils. Scrambling plants and root climbers were less common, accounting for 6.5% and 2% of the species, respectively. No family comprised scrambling climbers exclusively; species using this mechanism belonged to several families, including Euphorbiaceae, Rubiaceae, and Icacinaceae. Root climbers belonged to Piperaceae, Araceae, and Schizaeaceae.

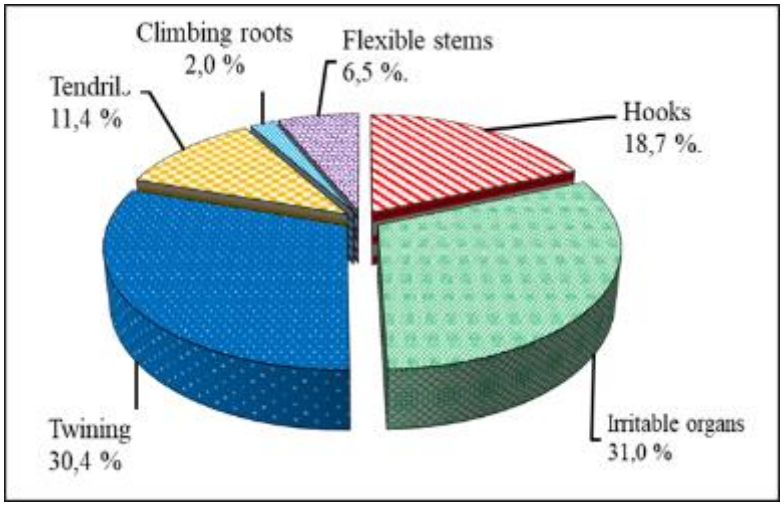

Figure 6: Distribution of climbing mechanisms among the climbing plant species recorded in Azagny national parc.

3.4 Relationships between anatomical structures and climbing mechanisms

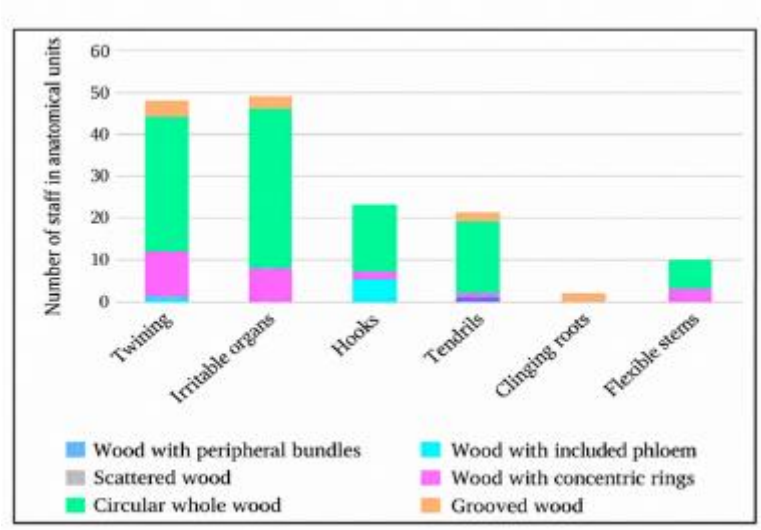

Figure 7: Numbers of species in each anatomical category, grouped by climbing mechanism.

Stem twiners displayed the greatest diversity of anatomical structures, with five types. Tendril climbers exhibited four types, whereas climbers with touch-sensitive organs, although the most species-rich group, exhibited three types (Figure 7). Hook climbers also exhibited three anatomical types. Single woody cylinders and concentric woody rings occurred in almost all climbing categories except root climbers. These were the only anatomical types recorded among scrambling climbers.

Climbers with a single woody cylinder accounted for more than 50% of the woody climbers. Wood with included phloem occurred in hook climbers and stem twiners but was uncommon in both categories. Concentric woody rings were absent from root climbers. This structure was uncommon among hook and tendril climbers but occurred in most stem twiners and climbers with touch-sensitive organs (Figure 8). Wood with peripheral vascular bundles was represented by one tendril-climbing species, *Paullinia pinnata*, whereas dispersed wood was represented by one stem-twining species, *Calycobolus africanus*.

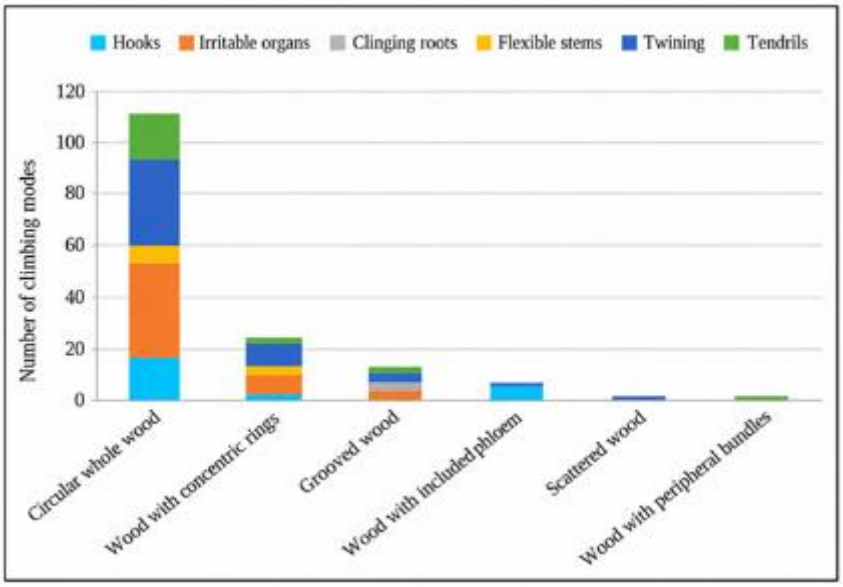

Figure 8: Numbers of species using each climbing mechanism, grouped by anatomical structure.

4 DISCUSSION

Climbers with touch-sensitive organs and stem twiners were the predominant climbing categories in Azagny National Park. The mechanisms by which climbing plants ascend their hosts play a major role in their abundance, diversity, and distribution. Because they can climb trees directly, stem twiners colonize a wide range of host trees. They are abundant in the canopy owing to their strength and ability to ascend directly. Twining also allows these climbers to remain sufficiently flexible to sway in the wind. Furthermore, stem twiners maintain close contact with their supports. Their stems tend to be more flexible, which reduces the risk of stem breakage if the support falls. Touch-sensitive organs, in turn, can coil more rapidly than twining stems and are characterized by their responsiveness to contact. These attributes enable both climbing categories to colonize all habitats. These findings are consistent with studies conducted in tropical forests [24, 25, 26].

Climbing mechanisms varied among botanical families. Many families exhibited only one mechanism. For example, Vitaceae and Passifloraceae were represented exclusively by tendril climbers, whereas Convolvulaceae and Menispermaceae were represented by stem twiners. Other families, including Apocynaceae, Celastraceae, and Fabaceae, exhibited several mechanisms. Families with a single climbing mechanism are predominantly composed of climbing plants, whereas those with several mechanisms include different life forms [20]. Several stem anatomical structures were recorded in Azagny National Park. Variation in cambial activity accounts for this anatomical diversity [27]. Some families exhibited more than one anatomical structure. For example, Menispermaceae included both single circular woody cylinders and concentric woody rings. The author of [28] showed that successive cambia evolved independently three times within this family and identified a predisposition towards their evolution. The regular single-cylinder structure has no conspicuous anatomical specializations and resembles the anatomy of self-supporting plants. Radiating wood, by contrast, has prominent rays visible to the naked eye. Furrows in furrowed wood result from the intrusion of non-lignified tissues, such as parenchyma or phloem. Successive woody bands comprise a more or less regular alternation of xylem and phloem. This compound structure results from secondary growth involving multiple cambia. Dispersed wood consists of separate vascular islands distributed diffusely within parenchyma and does not conform to a conventional anatomical arrangement. Cambial variants can therefore generate distinct anatomical structures that may influence stem mechanical properties. The study in [29] examined variation in the mechanical properties of climbing plant stems in relation to climbing mechanisms. These properties depend on internal stem structure, or anatomy, as well as stem geometry. Such differences may be related to climbing plant life strategies. Among the woody climbers recorded in Azagny National Park, the single circular woody cylinder was the predominant structure and resembled the anatomy of self-supporting plants.

Unlike climbing mechanisms, these anatomical structures were not necessarily characteristic of a particular habitat. Previous studies [22, 23] investigated possible functional or evolutionary relationships between stem anatomy and climbing mechanisms but did not establish a clear link. They nevertheless qualified the relationship between anatomical complexity and climbing specialization by showing that simple anatomies are not restricted to plants with simple climbing mechanisms. Indeed, several wood types occur among stem twiners. Although some associations between climbing organs and anatomical structures were observed in the present study, no definitive relationship could be established. Some anatomical structures were, however, restricted to particular families. For example, wood with peripheral vascular bundles was restricted to Sapindaceae and consequently to the climbing mechanism represented by this family, namely tendrils. Some species are known to develop lobed or flattened stem cross-sections independently of contact with a support. This represents a response to the transition from the self-supporting to the non-self-supporting growth phase, as in *Acacia kamerunensis*, *Iodes liberica*, and *Combretum racemosa*. In these species, lobed or flattened outlines result from reduced or preferential cambial activity at particular points around the stem circumference.

5 CONCLUSION

This study improved knowledge of the biological, morphological, and anatomical diversity of climbing plants and provided information on 158 species recorded in Azagny National Park. Three stem shapes were identified: cylindrical, flattened, and lobed. The park also harbored a diversity of anatomical structures and climbing mechanisms. Variation in cambial activity accounts for the diversity of anatomical structures. The single circular woody cylinder was the most common structure and resembled the anatomy of self-supporting plants. Six climbing mechanisms were recorded: stem twining, touch-sensitive organs, tendrils, hooks, clinging roots, and scrambling. Climbers with touch-sensitive organs and stem twiners were the most species-rich groups. No definitive relationship between climbing organs and anatomical structures could be established, although some anatomical structures were restricted to particular families.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

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Disclosure of conflict of interest

The authors declare that they have no conflicts of interest relating to this article.

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