TẠP CHÍ KHOA HỌC
TRƯỜNG ĐẠI HỌC SƯ PHẠM TP HỒ CHÍ MINH
HO CHI MINH CITY UNIVERSITY OF EDUCATION
JOURNAL OF SCIENCE
Tập 20, Số 9 (2023): 1554-1566
Vol. 20, No. 9 (2023): 1554-1566
ISSN: 2734-9918
Website: https://journal.hcmue.edu.vn
https://doi.org/10.54607/hcmue.js.20.9.3797(2023)

Research Article

THE ARCHITECTURE AND MORPHOLOGY OF *Pinus krempfii* Lecomte.

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Received: April 17, 2023; Revised: May 05, 2023; Accepted: May 23, 2023

ABSTRACT

The endemic species Pinus krempfii Lecomte in Bidoup National Park – Lam Dong Province, Vietnam is monopodial woody within morphogenesis and architecture based on Rauh's model. With a monopodial structure, it is featured with rhythmic branching, lateral flowering, radial symmetry, and the architectural unit within 5 axes. On morphological development, the P. krempfii consists of three main stages: seedling, sapling with five phases getting along with the arising of the first axis to 5th*, and the adult carrying reproductive organs and a complete architectural unit. Respectively, the transition of needle morphology and size is observed: wide, slender falcate, bundle with two leaves from a short shoot only on seedling and sapling trees. The adults, in addition, bundle with smaller, lanceolate leaves from a short shoot spirally. Essentially, the modification of leaves corresponds to the stages of morphogenesis: the size of leaves decreases with stages on average.*

Keywords: morphogenesis; ontogenesis; plant architecture; *Pinus krempfii*; Rauh's model

1. Introduction

Vietnam is one of the hotspots for conifer conservation according to the IUCN/SSC Conifer Specialist Group classification. Coniferous forests in Vietnam have an important ecological and economic role because of their wood properties, and many conifers have medicinal effects. *Pinus krempfii* Lecomte is classified as vulnerable according to the Vietnam Red Book (2007) or Endangered according to the IUCN Red List due to the decline in their distribution (Thomas et al., 2013). This endemic species of Vietnam has been recorded in the southern highlands of Vietnam, found mainly in Lam Dong, and is recorded in mixed forests in Bidoup – Nui Ba National Park, Lam Dong province. The economic value of this species is not exceptional (Farjon et al., 2004), but it is scientifically significant because of its many unique characteristics among gymnosperms such as broad falcate leaves growing in pairs on a short shoot.

Cite this article as: Tran Thanh Duy, Nguyen Phi Nga, & Luu Hong Truong (2023). The architecture and morphology of *Pinus krempfii* Lecomte.. *Ho Chi Minh City University of Education Journal of Science, 20*(9), 1554-1566.

For the ontogenesis of *Pinus krempfii*, at the stage of seedling to sapling, the leaves are often large, are shade-tolerant leaves, and each branch has two leaves and spiral alternates along the stem and branch axis. At the immature stage, the trees can have from one to four axial steps, young branches and small branches often grow in a horizontal direction (plagiotropic), and branches tend to twist to create bilateral symmetry, optimally receiving light under the canopy. Adult trees may have 4-5 axes, the upper branches have a well-spaced spiral structure, and the twigs radiate from the parent and tend to grow upward (orthotropic) with small and thick leaves. Changes in plant structure can be significant in adaptation to light conditions. Along with other species in the genus *Pinus*, *P. krempfii* has morphological features: Saplings begin to appear falcate-shaped leaves, growing in pairs on a small branch, 0.5-1cm in diameter, about 15-20cm high. Immature trees appear in axes from level 2 to level 4, height from 30 to 200cm, trunk diameter about 0.6-30cm. Mature trees are large, evergreen trees, 15-35m tall, 0.7-1.5m in diameter, pinkish-brown in color, flaking in patches (Farjon, 1984; Ickert-Bond, 2001).

The leaves of *P. krempfii* have been of great interest to researchers over the past century. The leaf structure has features such as two leaves appearing from a small branch (short-shoot), but the leaves are broad-leaf and falcate-shaped like those in the Podocarpaceae family (Buchholz, 1951). Leaf scales often fall off prematurely (Buchholz, 1951; Rollet, 1955) and deficiency of tracheal rays anatomically (Hudson, 1983; Ickert-Bond, 1997; Rollet, 1955).

2. Materials and methods

2.1. Sampling

We collected samples in a 25-hectare permanent plot belonging to sub-zone 90-90A in the area of Giang Ly – Bidoup National Park – Nui Ba. This plot was established and investigated by the Southern Institute of Ecology in 2016 with the presence of *P. krempfii*. Our observations were made on individuals in the sample plot with full morphological stages (about 150 individuals). The number of trees corresponding to each stage is 10-20. The descriptions were carried out with plants from the seedling to adult stages for two years 2016-2017.

2.2. Morphological and architectural analysis

The methods proposed by Hallé and Olderman (1970) allow observing and describing the morphological details of the tree with the following criteria: structure (monopodial/sympodial), growth process (continuous/rhythmic), phyllotaxis of stem/branch, symmetry (bilateral/radial), branching pattern (continuous/rhythmic/diffuse), growth unit (morphology, growth process), flowering apical meristem, and reiteration (total/partial; sequential/opportunistic).

Usually, we define morphological stages based on the number of axes. The later morphological stage usually increases by one axial order compared to the previous morphological stage (Hallé, Oldeman, & Tomlinson, 1978; Mathieu, Cournède, Barthélémy, & Reffye, 2008; Sabatier & Barthélémy, 1999). The results of the morphological analysis of each stage are recorded with a morphological analysis table and outlined by drawings. At the mature and stable stage, we establish an architectural description table, which clearly shows an architectural unit and helps us to define an architectural model for the species. (Barthélémy & Caraglio, 2007)

Architectural unit tables show us the differentiation among the axes and delineate the growth stages and architectural reiterations. Such repetition can be at several levels: the entire tree's axes (total reiteration) or a part of the initial crown (partial reiteration) (Edelin, 1981). The phenomenon of architectural reiteration is often observed in the adult stages, many authors suppose that it is significant to increase the size of the canopy, helping the tree to optimize the surface to absorb light (Edelin, 1984; Hallé et al., 1978). Finally, we reviewed all the different developmental stages and produced a morphological ontogenesis diagram of *P. krempfii*. Ontogenesis is understood as a collection of morphological features that appear sequentially in the life cycle of a plant. At each life stage, plants have morphological and adaptive features in the life process. Understanding the modifications in plant morphology during the life cycle, we suggest manipulation in conservation to ensure the best growth of plants.

3. Results and discussion

3.1. Seeding stage

Seedlings usually have a height of less than 10 cm and grow close to the ground, at the forest floor, with a diameter of about 1 mm. The number of cotyledons ranges from 8 to 11 leaves that radiate from the stem. Cotyledons are usually thin, with a surface area of about 2.5 to 3.5 cm2. The leaf blade is flat, falcate-shaped, thin, and varies in size from 2.4 to 3.5 cm in length and 0.6 to 1 mm in width.

Plants germinate under an open canopy in the forest, the surrounding space is open (Figure 1a).

Figure 1. *(a) Seedling of P. krempfii.; (b) Sapling through the seedling stage; (c) Sapling stage 2 leaves in pairs consisting of two large, falcate-shaped leaves arising from a very short shoot, leaves; (d) Sapling phase 3 with two axes with the branches; (e) Two leaf forms in adult trees: small leaves (top) and large leaves (bottom)*

3.2. Sapling stage

3.2.1. Sapling phase 1

At this stage, the tree has a height of more than 10 cm to less than 20 cm. The tree structure has only 1 main stem and secondary growth, and the average diameter is 2 mm. Leaf morphology has a transition in the early stages of ontogenesis with falcate leaves spirally alternate growing after the cotyledon stage. Leaves at this stage grow closely together with an average spacing of 2 mm and the average total leaf area is about 26.5 cm^2.

The main stem is monopodium and develops in a rhythm, radially symmetrical, and the leaves are alternately spiral and unbranched. The leaves are small, dark in color, and grow singly. The growth units at this stage are evenly distributed along the stem axis and are distinguishable as very short internodes appear at the end of a growth unit. The average number of growth units is 15 (Figure 1b).

3.2.2. Sapling phase 2

This stage witnesses differences in leaf morphology and architecture. Plants at this stage usually have a height of over 20 cm to less than 30 cm, with an average diameter of 3 mm. Leaf morphology varies from small, solitary leaves to very large falcate leaves, which grow in pairs from a very short shoot. The average area is about 2.5 cm^2 for each single leaf. (Figure 1c)

3.2.3. Sapling phase 3

The third sapling stage has a significant increase in main stem diameter (4-6 mm) with a maximum height of less than 150 cm and a second axial level has appeared. The feature of branching is that the branches arise in rhythm and are immediate, the branches also grow in a spiral alternate manner along the stem axis (mesotonic). The second axis (branch) is monopodium, rhythmic with large falcate leaves. Branches tending upward (orthotropic) but with the outermost part with leaves spiraling very closely together around an upward shoot indicates that the leaf arrangement is still in a spiral alternate pattern and, as a consequence, produces a planar with radial symmetry components (Figure 1d).

The shoots in this period show an equivalence. However, the number of growth units of the upper branches is usually 1 unit smaller than the number of growth units of adjacent lower branches. Observing the base of the branch, traces of shoot scales and very short internodes can be seen, suggesting delayed branching. Thus, the growth rhythm between the two axes lags together creates a general development trend of the axes of *P. krempfii*. This stage usually undergoes 5-6 growth units along the stem (Figures 2a and 2b).

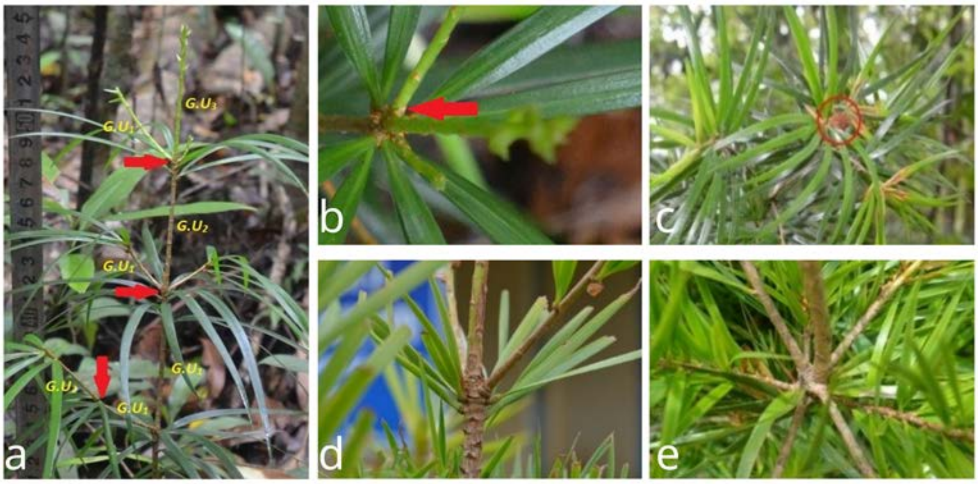

Figure 2. *The late growth between the axes is based on the correlation between the number of growth units (a) and; (b) Traces of shoot scales and short internodes at the base of branch A2 represent delayed branching; (c) Injury shoots on a 5th phase sapling. (d) Part of the A4 on an adult tree with a spiral alternate phyllotaxy and numerous shoot scars; and (e) branches radiating from a point*

3.2.4. Sapling phase 4

Following the third phase sapling stage, the fourth phase sapling stage has the emergence of the third axial order. The main stem diameter has increased to 0.9 cm with a maximum height of no more than 190 cm. The third axis is usually short and tends to grow upward (orthotropic) with the leaves concentrated in the outermost part of the axis in a spiral alternate manner and a radial symmetry. Along the second axial order, the third axis has a rhythmic growth with a continuous structure, and the leaves grow in a spiral alternate pattern. However, due to the twisting of the shoots during development, the leaves tend to have a surface distribution that spreads out to the sides during the development of the branch, which makes branches likely horizontal in the middle (plagiotropic) and up towards the top (orthotropic). In general, the growth of branches during this period tends to be radial at the outermost part and bilaterally symmetrical along the axis.

3.2.5. Sapling phase 5

The fifth sapling stage has a relatively long growth period, over 2m to less than 10m in height, the trunk diameter can reach 2.4 cm. This is an important transitional stage of development before entering adulthood. The sapling phase 5 has four axes. The second axial order is the branch with plagiotropic divergence and twistedly distributed leaf shoots combined with the twisting of the shoots to form bilateral symmetry. The outermost part of the axis develops upward (orthotropic) with the leaf shoots distributed in a radial symmetry pattern. The branches at the top of the trunk tend to be more upward. In particular, some saplings at stage 5 appeared injured buds (Figure 2c).

3.3. Adult stage

At this stage, the branching is still rhythmic. The branches usually perform the acrotonic, and the overall direction of the branches is orthotropic. At the same time, there is a great change in leaf morphology. The leaf area is smaller, and leaves growing around the axis in the direction of the spiral alternate is more clear. The color of the leaves is lighter than that of the leaves in the younger stages. However, there are still two types of leaves at the adult stage: large leaves - dark color and small leaves - light color. The canopy has a typical dome shape. Completely radial symmetry with the appearance of reproductive buds is lateral cones. The phyllotaxy on the axis is still spiral alternate and more clear than in the previous stages. This clearly shows that the scars left by the fallen shoots, creating a rough surface along the branches (Figure 2d). The arrangement of branches is spiral alternate, and at the ends of the growth unit, branches are arising close together, from 4 to 5 branches radiating from a point (Figure 2e).

Partial and sequential architectural reiteration in adult trees occurs mainly at the A2 and A3 axis levels. This architectural reiteration repeats a part of the architecture (from A2 to A5 if growing on the A2 axis or from A3 to A5 if growing on the A3 axis) and follows the growth cycle of the tree, not necessarily due to branches damaged. This should be considered as a *sequential reiteration*. This architectural reiteration contributes to the natural extension of the canopy.

3.4. Morphological characteristics

The *P. krempfii* has a typical Rauh's architecture, indicating that the species is adaptable to diverse lighting conditions. The sapling stage has a radial symmetry and a horizontal branch structure (plagiotropic) to capture light under canopy conditions. However, in populations, a small number of young trees have shown poor adaptation to under-canopy conditions. Very few trees can complete their architecture in the mature stage due to poor competition with the trees that are broad-leaved and are caused by the hollowing of the trunk (Nguyen, 2012). Trees reaching maturity have the architectural perfection of Rauh's model with radial symmetry, orthotropic branches, diminishing leaf size, and distinctly distributed in spiral alternate phyllotaxy. Contemporary, at the adult stage, there was also a reiteration from the axis 2 in trees with a trunk diameter of 25cm. Morphology and architecture at the adult stage show a strategy of adapting to strong light when distributed in low-humidity areas and strong lighting conditions in steep hills and hilltops (Nguyen, 2012; Le & Nguyen, 2012). Adult trees usually grow in sloping and open hillside areas, where light conditions are favorable for photosynthesis. Adult trees have two types of leaves: falcate, large, elongated leaves and lanceolate, small leaves. The small, lanceolate leaves usually appear on the terminal axis (A5) and grow in pairs from a short shoot similar to falcate leaves, but the distribution of the shoots (short shoot) on the axis is in a spiral alternate phyllotaxy, ensures light absorption of the entire canopy (Quach & Nguyen, 2021) as well as photosynthesis and water transport (Ishii & Asano, 2010; Ishii, Azuma, & Nabeshima, 2013). Recently, a detailed leaf anatomical study by Ickert-Bond (2000) on large leaves shows that stomata are distributed on both leaf surfaces. The “scissor” structure of two leaves growing from a small branch shows that one leaf is dorsal and the other ventral to light (upper), with such observations, Ickert-Bond asserts the distribution of stomata in leaves of *P. krempfii* to be bipartite, adapted to light conditions under the canopy because large leaves often appear in seedlings and saplings and proposed to delineate two types: (1) shade-tolerant leaves (instead of the term *immature leaves*) are large and (2) shade-avoidance leaves ("sun" leaves) are smaller. In addition, the conical canopy of the Rauh’s architecture is formed with the sequential reiteration of the axis 2 to optimize the photosynthetic structure, helping the tree compete more effectively in the canopy and beyond.

3.5. Architectural analysis

The architecture of the species *P. krempfii* has features of the Rauh’s model (Hallé et al., 1978): rhythmic growth pattern, rhythmic branching, synchronous shoots, lateral reproductive shoots, and radially symmetrical pattern. The bilateral symmetric growth of the axis is often commensurate with the horizontal growth pattern, suitable for low light conditions because these branches are often concentrated in the lower part of the forest canopy (Ninemets & Kull, 1995). Meanwhile, in the adult stages, the branches tend to be orthotropic and are characterized by radial symmetry, the leaves become smaller and paler to adapt to strong and direct light (Easlon & Bloom, 2014; Wolf, Carson, & Brown, 1972).

The results obtained on morphology and architecture through the developmental stages of *P. krempfii* help to outline an architectural unit of the species consisting of five complete categories of axes. These types of axes describe in detail the morphological and architectural features of each axis level (Table 1).

Table 1. *An Acrhitectural Unit of P. krempfii*

Trunks (A_1)	**Branches (A_2)**	**Branchlets (A_3)**	**Twigs (A_4)**	**Brachyblasts (A_5)**
Monopodium Rhythmic growth Adjacent growth units by short internodes	Monopodium Rhythmic growth Adjacent growth units by short internodes	Monopodium Rhythmic growth Adjacent growth units by short internodes and very close short shoots with pairs of leaves	Monopodium Rhythmic growth Adjacent growth units by short internodes and very close short shoots with pairs of leaves	Monopodium Rhythmic growth Adjacent growth units by short internodes and very close short shoots with pairs of leaves
Orthotropic	Plagiotropic in the middle then Orthotropic at the tip of the axis	Plagiotropic in the middle then Orthotropic at the tip of the axis	Orthotropic	Orthotropic
Radial symmetry	Bilateral in the middle; Radial at the tip	Bilateral in the middle; Radial at the tip	Radial symmetry	Radial symmetry

Delayed branching, Rhythmic branching, acrotonic	Delayed branching, Rhythmic branching, mesotonic	Delayed branching, Rhythmic branching, mesotonic	Delayed branching, Rhythmic branching, acrotonic	Unbranched
Spiral alternate phyllotaxy (branches and leaves)	Spiral alternate phyllotaxy (branchlets and leaves)	Spiral alternate phyllotaxy (twigs and leaves)	Spiral alternate (brachyblasts and leaves)	Spiral alternate phyllotaxy (leaves)
No flowering	No flowering	No flowering	No flowering	Lateral flowering (male and female cones monoceous)
Reiteration unobserved	Sequential reiteration from the order A2, single level.	Sequential reiteration from the order A3, single level	Reiteration unobserved	Reiteration unobserved

Sequential reiteration is also observed mainly in adult trees, in the high canopy and often beginning to repeat the A1 to A3 axes. This is a biological feature in the development of this species that enhances the canopy structures to accommodate photosynthesis and reproduction (Hallé & Oldeman, 1970; Ishii & Asano, 2010; Millet, Bouchard, & Edelin, 1999). The architectural reiteration structure repeats the axial steps corresponding to its position on the axis sequentially and contributes to the canopy as part of the canopy structure process. Axis levels of architectural reiteration structure generally have a repetition of previous axes, but in reiteration axes from A3' to A4' (repetition of axis steps A3 and A4), there is a slight difference. During shoot growth reiteration A3' and A4', there is faster shoot growth and a radial structure due to leaves with a more regularly spiral alternate pattern.

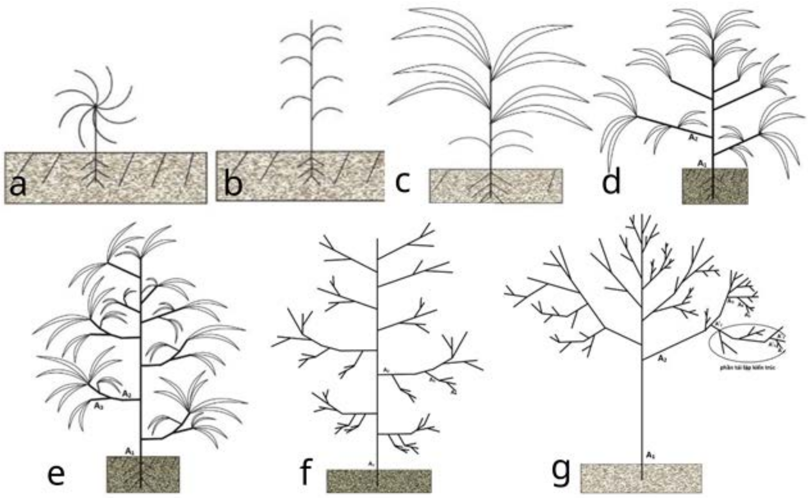

Figure 3. *Diagrams of (a) seedling; (b) sapling 1; (c) sapling 2; (d) sapling 3; (e) sapling 4; (f) sapling 5 and (g) adult tree with 5 axes and a reiteration on the A2 order*

The morphogenesis of *P. krempfii* can be divided into three main stages: (1) seeding; (2) sapling, and (3) mature tree (adult). In particular, the sapling stage has a relatively long ontogenesis and is quite complex through the creation of sequential axes from A2 to A4.

(1) Seedling: The stage has only one axis and forms from 8 to 11 cotyledons. Leaves are small needle-shaped, curved to the right, pale in color, and radiating evenly around the apical shoot (Figure 3a).

(2) Sapling: The sapling stage is divided into five phases corresponding to the number of axes in which it occupies:

Sapling 1: This stage established the initial leaf arrangement of the axis as a spiral alternate and that the development of the axis was rhythmic through growth units marked by very small internodes between the adjacent leaves (Figure 3b).

Sapling 2: The phyllotaxy of the large leaves during this period is still regularly spiral alternate, forming a canopy structure with radial symmetry and a regularly rhythmic growth process (Figure 3c).

Sapling 3: Branch development is delayed to the main stem (delayed) and can be seen as evidence of lateral bud stalling as small closely spaced scales or very short internodes at the base of the branch. Typically, the main stem grows faster than the branches in an architectural unit (Figure 3d).

Sapling 4: The third axis arises along the second axis and has an orthotropic structure, the leaves are spiral alternate and radially symmetrical. Due to the increase in the mass and size of the branch as well as the effect of gravity, the second axis changes the direction of the branch, which is the horizontal branch in the middle (plagiotropic), then transitions up (orthotropic), resulting in symmetry. The branch symmetry also transitions from bilateral symmetry (in the horizontal segment) to radial symmetry (in the upward segment) (Figure 4e).

Sapling 5: In general, branches from A2 to A3 have a similar radial and branching transition pattern, i.e. plagiotropic direction and bilateral symmetry turning orthotropic and radial symmetry. In addition, at the end of axis 2, the branches still follow a regular spiral alternate pattern, creating a radial symmetry. The twisting of the branches on the young plant stage 5 is also quite strong, especially for the branches in the lower part of the trunk: symmetry of branches (from two sides to radial), branch orientation (from plagiotropic to orthotropic), branching with a transition from bilateral to spiral symmetry, twisting of branches in an orthotropic tendency, and occasionally found injured shoots on the axis 4 (Figure 4f).

(3) Adult tree: the adult tree stage establishes 5 axes. The important change of this stage is the appearance of reproductive buds and the formation of the typical cone-shaped canopy structure of gymnosperms. The important morphological and architectural changes of this period are: A3 and A4 grow along the main axis in a spiral alternate manner, but due to the twisting of the axes as well as the internodes being too short, the form is same as the *opposite* growing pattern, establishing a bilateral symmetry in the middle part of the branch. Moreover, the direction of branches at the top of the trunk is orthotropic, giving rise to the characteristic canopy structure of *P. krempfii* with a conical shape (Figure 4g).

The adult stage is also characterized by the parallel existence of two types of leaves: large dark leaves, which appear from the sapling stages, and small light leaves, which appear mainly at the top of the adult tree. The dark and large leaves belong to the canopy structure in the lower part of the plant, and the high amount of chlorophyll helps it to perform the function of efficient photosynthesis. While the small, light-colored leaves usually belong to the upper part of the canopy, reducing leaf area helps the canopy to reduce photosynthesis, focusing energy for more efficient reproduction (Johnson, Smith, Vogelmann, & Brodersen, 2005; VILE et al., 2005; Wilson, Thompson, & Hodgson, 1999). Architectural reiteration contributes to the canopy structure in adult trees to form a complete canopy structure (successful reiteration complex).

Studies on *P. krempfii* show that in the species communites, *P. krempfii* is often associated with some other gymnosperm species such as the long-leaved bamboo pine (*Podocarpus neriifolius*) or the white cedar (*Dacrycarpus imbricatus*) (Do, 2015). Co-existing with species of the Podocarpaceae family with the characteristic "broad-leaf," the species P. *krempfii* exhibits architectural similarities with *P. neriifolius* such as rhythmic axial growth, distinct growth units by short internodes and closely spaced scales or leaves. There is a transition from plagiotropic to orthotropic branching for saplings under canopy conditions. However, under canopy conditions, *D. imbricatus* exhibits a clear bilateral symmetry and orthotropic branching, *P. neriifolius* tends to have orthotropic branches, while the branches of *P. krempfii* grow plagiotropic and then orthotropic steadily. This feature in *P. krempfii* shows the ability of this species to adapt morphologically and architecturally when changing the direction of branches to optimize light absorption under canopy conditions. The architectural patterns of *P. krempfii* and *P. neriifolius* species are similar when following the Rauh's model, such as rhythmic growth, rhythmic branches, and a tendency to spread evenly around the trunk. The Rauh's model commonly found in gymnosperms and especially in genus Pinus helps the plant to quickly adapt when the apical shoot on the main stem is damaged, the lateral shoots will quickly grow to replace the main stem (Hallé et al., 1978).

4. Conclusion and recommendation

4.1. Morphological and Architectural Characteristics

The architectural unit of *P. krempfii* species includes five levels of axes, including:

- The axes have a *monopodium* structure and develop in full *rhythmic growth*. The growth of shoots on the axes is equivalent.
- *Lateral branching* and all the axes tend to rise with *radial symmetry*. The branching is in a *delayed* pattern, and the phyllotaxis of leaves and branches is spiral alternate.
- Rhythmically steady growth units marked by slowed shoot growth, manifested by the appearance of *short internodes*, sometimes by the appearance of double leaves growing from a very short shoot close together.
- Reproductive shoots grow lateral.
- Sequential and partial reiterations that contribute to the complete canopy structure.

Those architectural features suggest that *P. krempfii* has an architectural model similar to the Rauh's one.

4.2. Conservation recommendation

This study examined the architecture and morphogenesis of *Pinus krempfii* Lecomte. to understand their individual development and the differentiation of shoots in development and contribute to understanding of the status of the species in nature.

The conservation of the species *P. krempfii* in Bidoup – Nui Ba National Park is in the stage of population investigation, establishment of sample plots, and strict protection zone. The conservation of the genetic resources of the *P. Krempfii* is extremely difficult and currently only achieved at the level of basic silvicultural investigation. Although this species has not been exploited much since its wood is of limited economic value, the expansion of agricultural land and economic development has affected its distribution area (Farjon et al., 2004; Nguyen et al., 2004; Nguyen, 2012). Greenhouse nursery and tissue culture activities have been carried out, but so far no significant results have been obtained (Le & Nguyen, 2012; Do, 2015). Thus, understanding the morphology and architecture of *P. Krempfii* helps researchers to have a comprehensive view of morphogenesis and, if combined with detailed anatomical studies, ecophysiology, and tree-ring research will help to better understand the adaptation strategy of *P. krempfii* in its evolution in the narrow distribution area of Bidoup – Nui Ba National Park. For more effective conservation of this endemic species, more in-depth research on individual developmental biology is needed to support planning for *in situ* or conservation and development of genetic resources *in vivo*.

❖ ***Conflict of Interest:*** *Authors have no conflict of interest to declare.*

❖ ***Acknowledgement:*** *This project would not have been possible without the support of many people. Many thanks to the staff of Bidoup – Nui Ba National Park and Southern Institute of Ecology, who gave us support for collecting and observing samples in the forest. Thanks to Saigon University for awarding me with the financial support to complete this project.*

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KIẾN TRÚC VÀ HÌNH THÁI CỦA LOÀI THÔNG HAI LÁ DẸT (*Pinus krempfii* Lecomte.)

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Ngày nhận bài: 17-4-2023; ngày nhận bài sửa: 05-5-2023; ngày duyệt đăng: 25-5-2023

TÓM TẮT

Loài Thông hai lá dẹt (Pinus krempfii Lecomte.*) là loài đặc hữu tại Vườn Quốc gia Bidoup – Núi Bà, tỉnh Lâm Đồng, Việt Nam. Pinus krempfii là loài thân gỗ, đơn trụ, có sự phát triển hình thái và kiến trúc điển hình của mô hình Rauh. Cây có cấu trúc đơn trụ, sự phân cành theo nhịp, các chồi sinh sản mọc bên, có kiểu đối xứng tỏa tròn và đơn vị kiến trúc hoàn chỉnh gồm có 5 bậc trục. Nhìn chung, căn cứ vào sự phát sinh hình thái, có thể thấy sự phát triển của loài P. krempfii gồm 3 giai đoạn chính là: cây mầm, cây non gồm có 5 pha tương ứng với sự phát sinh các bậc trục từ 1 đến 5 và cây trưởng thành đã xuất hiện chồi sinh sản cùng với sự phát triển hoàn thiện của một đơn vị kiến trúc. Bên cạnh đó, sự thay đổi hình thái và kích thước lá cũng được ghi nhận: cây mầm và cây non chỉ có một loại lá có dạng hình liềm, mọc thành đôi từ một chồi ngắn và có kích thước lớn, trong khi đó, cây trưởng thành có sự xuất hiện lá nhỏ, cứng, mọc xoắn cách sát nhau. Nhìn chung, sự thay đổi hình thái và kích thước lá tương ứng với sự phát triển hình thái của P. krempfii qua các giai đoạn kiến trúc: kích thước lá trung bình có xu hướng nhỏ dần từ cây non đến cây trưởng thành.*

Từ khóa: phát sinh hình thái; phát triển cá thể kiến trúc thực vật; *Pinus krempfii*; mô hình Rauh