Is leaning trees of *Vatica pauciflora* (Korth.) Blume related to their crown architecture?

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Abstract. *Vatica pauciflora* (Korth.) Blume (Dipterocarpaceae) or locally known as resak rawa is an important tree. It is categorized as vulnerable regarding the IUCN (International Union for Conservation of Nature) Red List of Threatened Species. We can find the resak rawa tree collection in the Bogor Botanic Gardens, which serves as a place for research and tourism. Due to the diversity in individual tree anatomy within species, understanding correlation among individual tree traits, particularly crown architecture and tree leaning, is of great interest. That will be important because the leaning trees and crown architecture will affect the risk level to the safety of visitors. We can also use the architecture of the tree crown to understand the factors that influence tree growth. This study aims to investigate the correlation between the leaning trees and the crown architecture of *V. pauciflora*. Eight heritage trees of the species in the Bogor Botanic Gardens at the age of 54–105 years old were purposely, sampled in this study. The variables observed were height, trunk and crown diameter, leaning tree, live crown ratio, and direction of the main branches. The results show that crown shapes will follow the leaning trees with a correlation of 0.97. The main branches will be longer in the direction of the leaning trees \( y=0.9956x+11.312; R^2=0.9431 \). Suggestions to the management of *V. pauciflora* are to provide information boards to visitors and pruning the crown in the direction of the leaning trees is needed. The findings could be used to formulate mitigation measures as to the risk and safety of visitors.

1. Introduction
Trees are woody plants that have a reasonably large size and height. Generally, trees have a main trunk that stands alone or branched [1]. The criteria for a tree are to have a primary trunk diameter of more than 20 cm [2], while a height of more than 6 m [3]. Trees provide benefits to humans, the environment, and the economic sector. Trees can also provide beauty, comfort, and health benefits. Trees planted in one location have various roles such as modifying the microclimate [4, 5], improving air quality, reducing water runoff and animal habitats [6, 7]. The presence of trees in urban areas is essential to providing environmental services [8, 9].

[1]
Botanic gardens are one of the green open spaces that make trees the main target in ex-situ conservation. Ecologically, botanic gardens can also become water catchment areas while reducing erosion, thermal comfort, air quality and contributing to the balance of the ecosystem [10]. The Bogor Botanic Gardens (BBG) is one of the botanic gardens located in urban areas. The existence of the BBG is proper in the heart of the city center of Bogor that is a vital oxygen provider for the surrounding communities. In addition to providing benefits to the environment, BBG is also one of the ecotourism-based objects that make the existence of large, old, and rare trees attractive and exciting.

*Vatica pauciflora* (Korth.) Blume is one of the tree collections in BBG that can be categorized as old/heritage (105 years), and its rarity status is classified as VU-vulnerable regarding the IUCN (International Union for Conservation of Nature) Red List of Threatened Species [11]. According to Coates [12], a heritage tree is a large tree, grows naturally, has an extraordinary value, and is irreplaceable because of its age or history. In addition, heritage trees can also be defined based on criteria, such as age, rarity, size, aesthetic/art, botanical, ecological, and historical values. The disadvantage of old trees is that they have a higher risk than young trees. Old trees tend to slant trunks, crown imbalance, susceptible to pests and diseases, susceptible to weathering and termite attack. In this study, trees categorized as old are more than 50 years old.

A leaning tree has a potential hazard to targets below it. Leaning trees exceeding 15° from the vertical may be recommended for felling [13]. Assessment of leaning trees is an essential component of risk assessment for hazardous trees [14]. While the shape of the tree crown is the most striking part and becomes an aesthetic value in urban areas [15]. The crown structure is also an expression as the central energy source of the tree [16, 17]. This study aims to investigate the correlation between the leaning tree and the crown architecture of *V. pauciflora*. That is important because the leaning tree and crown architecture will affect the level of risk to the safety of visitors. Thus, it is expected to increase understanding of the factors that affect tree growth and improve visitor safety in the public green space.

**2. Method**

The research researched April-June 2021 at the Bogor Botanic Gardens, Indonesia (figure 1). The sampled trees used were eight trees with more than 50 years of age (figure 1) with purposive sampling. The method for morphological characteristics is to categorize the leaning tree with a clinometer, 86–90° is an upright tree, < 86° is a leaning tree, and the main branch and leaning tree direction (°) with a compass. Then measure tree height (m) [18], live crown ratio (LCR, %) with a clinometer, crown diameter (m) with roll meter [19] (figure 2), and diameter at breast height (DBH, cm) with phi band. The condition of the research location with land slope <8% (flat), no hardening structure nearby, clay soil texture, low-moderate Soil Organic Carbon (SOC) [20]. BBG is a tropical climate with a height of 231–270 masl, rainfall of 3,712 mm/year, daily temperatures of 20.1–29.4 °C, and humidity of 35–99% [21]. The data analysis included regression and Pearson correlation of observational variables.
Figure 1. Location of Bogor Botanic Gardens (BBG) and *Vatica pauciflora* trees.

Figure 2. Measuring of tree height and crown diameter.

\[ h = s(\tan \alpha + \tan \beta) \]

\[ LCR = \frac{h - s(\tan \beta + \tan \gamma)}{h} \times 100\% \]

- **h** = tree height
- **s** = tree-viewer distance
- **LCR** = live crown ratio

*Horizontal crown*

\[ Crown \ diameter = \frac{(a + b)}{2} \]

- **a** = longest diameter, **b** = shortest diameter
3. Results and Discussions

3.1. Morphological characteristics

Growth is generally influenced by two main factors, namely genetic and environmental factors. Genetics is a factor that is inherited and will form a feature of the trees. In contrast, environmental factors are the ones that affect the growth and development of trees, such as temperature, humidity, light, nutrients, and water. Both play a critical role, influence each other, and are interpreted in terms of morphological characteristics. Trees have main parts, including roots, trunks, leaves, and fruit. In this study, the main characters observed are trunks and leaves. The result interpreted the two main elements in terms of height, live crown ratio, diameter, leaning, crown diameter, and main branch direction variables. The morphological characteristics of *Vatica pauciflora* are presented in table 1.

| Tree | Leaning tree | Categorie s | Height (m) | LC R (%) | DBH (cm) | Crown diameter (m) | Direction of the main branches (°) | Stand age (years) |
|------|--------------|-------------|-----------|----------|----------|--------------------|----------------------------------|-----------------|
| a    | Upright      | 88          | 19.47     | 80       | 52.5     | 14.8               | NO / C                           | 61              |
| b    | Upright      | 88          | 18.02     | 90       | 45.5     | 11.2               | NO / C                           | 105             |
| c    | Upright      | 87          | 29.79     | 44       | 50.0     | 9.0                | 290 / W; 197                     | 54              |
| d    | Leaning      | 85          | 24.45     | 85       | 36.5     | 9.6                | 291 / W                          | 61              |
| e    | Leaning      | 83          | 33.74     | 51       | 45.5     | 11.2               | 15 / N                           | 54              |
| f    | Leaning      | 76          | 17.87     | 90       | 30.0     | 7.4                | 240 / SW                         | 61              |
| g    | Leaning      | 77          | 14.92     | 82       | 25.0     | 7.9                | 320 / NW                         | 61              |
| h    | Leaning      | 84          | 30.08     | 75       | 71.5     | 11.5               | 327 / NW                         | 61              |

Note: LCR = live crown ratio; DBH = diameter at breast height.

The measurement results of *V. pauciflora* trees can be grouped into two categories based on the leaning patterns of the main trunk. The first category is upright with a leaning of 86–90° in a total of three trees (a, b, and c), while the second category is leaning with a leaning of less than 86° in a total of five trees (d, e, f, g, and h). Tree height varies, with the lowest minimum of 14.92 m and the highest of 33.74 m. Live crown ratio ranges from 44–90%, with a crown diameter of 7.4–14.8 m. The lowest trunk diameter/DBH is 25 cm, and the highest is 71.5 m. Tree height was positively correlated with primary trunk diameter, similar to the research results by Sharma [22] and Feldpausch [23]. The observations of *V. pauciflora* have the direction of the main branch and the leaning tree in the north to the southwest range.

3.2. Leaning trees and direction of the main branch

Based on leaning trees and direction of the main branch, *V. pauciflora* could be categorized into two groups, i.e. (1) upright tree is the trees that have a leaning of more than 86° (Figure 3a-c), and (2) sloping trunked tree is trees with a leaning of less than 86° (Figure 3d-h). Upright trees have a more symmetrical crown shape with the direction of the main branches spreading, approaching a circle. The main trunk is more likely to be in the center of the crown. Whereas in sloping trees, the direction and length of the main branch are more inclined towards the direction of the leaning trees, which is indicated by the red arrow. That is supported by the correlation analysis between the two leaning tree direction variables and the main branch direction very strongly correlated (0.97; table 2) with a regression value of \( y = 0.9956x + 11.312; R^2=0.9431 \) (figure 4).

Table 2 describes the correlation between the factors observed in this study. A very strong positive correlation exists between the direction of the leaning tree and the direction of the main branches (0.97), height and crown diameter (0.95), height and standing age (0.93). A strong correlation exists between leaning tree and height (0.80), leaning tree and crown diameter (0.86), diameter at breast height and...
crown diameter (0.85). That shows that a taller tree and larger diameter of a crown, higher learning of a tree. The size of the crown diameter is also positively correlated with height and DBH.

Table 2. Correlation between factors (see values below the diagonal).

| Direction of leaning tree | Direction of the main branches | Leaning tree | Height | LCR | DBH | Crown diameter | Stand age |
|---------------------------|-------------------------------|--------------|--------|-----|-----|----------------|-----------|
| 1                         | 0.97                          |              |        |     |     |                |           |
| Direction of the main branches |                               |              |        |     |     |                |           |
| Leaning tree              | -                             | -            | 1      |     |     |                |           |
| Height                    | -                             | -            | -0.80  | 1   |     |                |           |
| LCR                       | -                             | -            | -0.44  | -0.80 | 1   |                |           |
| DBH                       | -                             | -            | 0.66   | 0.75 | -0.40 | 1              |           |
| Crown diameter            | -                             | -            | 0.86   | 0.95 | -0.73 | 0.85           | 1         |
| Stand age                 | -                             | -            | -0.27  | -0.67 | 0.93 | -0.12          | -0.50     |

Note: 0.00–0.10 = negligible; 0.10–0.39 = weak; 0.40–0.69 = moderate; 0.70–0.89 = strong; 0.90–1.00 = very strong [24]; LCR = live crown ratio; DBH = diameter at breast height.

Figure 3. The shape of the horizontal crown and direction of the leaning trees.

Figure 4. Regression of leaning trees and main branch directions.
Figure 5. The shape of the vertical crown and direction of the leaning trees.

Leaning trees can increase the risk of falling and hitting anything in their crown zone. The zone potentially affected when a tree falls is approximately one time the tree's height [25]. Similarly, tree sketches made vertically (figure 5 d-h) show that the shape of the tree crown tends to be more significant in the direction of the leaning of the tree trunk. Usually, upright trees, newly formed xylem cells from the vascular cambium become lignified and produce tensile stresses in the longitudinal direction and compressive stresses in the tangential direction. This combination of stresses around the vascular cambium will result in regular stress distribution in the diametrical plane. As a result, tensile stress is formed on the outside and compressive stress inside of the rod. This stress is a critical factor in helping tree trunks withstand wind [26]. So that if the primary rod condition is tilted, it will reduce the stress generated by the tensile and compressive stresses in the rod. In the end, it will reduce the tree's ability to withstand wind.

The leaning of *V. pauciflora* tree is not affected land slope because all trees grow in an environment with a slope of <8%. In this case, the quality of the site also does not affect because the tree grows in a location with a moderate C/N ratio (14.12) and a moderate CEC (22.81±2.60 cmol(+)/kg) [20]. However, leaning trees are affected by phototropism, which makes sunlight a major environmental factor in tree growth, flowering, and shaping. The leaning tree is caused by one-way light deforming the tree [27]. The eccentric radial growth on the tree can strengthen the branches. But this is not enough to overcome the gravitational force of the weight of the branches grown as a result of this growth [28].

The direction of the leaning tree was positively correlated with crown height and diameter but negatively correlated with LCR. That shows the larger diameter of the crown, taller tree, higher angle of inclination of the main trunk. Thus, the recommendation given as a precaution in reducing the risk of falling trees to visitors includes: first, providing information boards showing the level of learning and
the danger. Second, for tree management, visitors are prohibited from doing activities under leaning trees because the crown load is heavier in the direction of the leaning tree. Third, in the management of leaning trees, pruning can be carried out on the crown in the direction of the leaning tree to reduce the load on the crown and minimize the risk of falling trees. Pruning can also be done on nearby trees to reduce competition for light. Pruning is an essential practice and can improve the health and aesthetics of the tree shape [29, 30]. This management must be carried out correctly and planned because if there is an error in planning, it can result in an asymmetrical tree shape and an unbalanced load [31]. After all, a vertical trunk is vital for a tree’s mechanical stability [27].

4. Conclusion
From the results and the discussion, we can conclude that the architectural form of the crown and the direction of the main branch of *Vatica pauciflora* follow the direction of the leaning tree. That is supported by the correlation between the two variables, which is 0.97 (very strong). Suggestions to management are to provide information boards to visitors, and pruning can be done on the crown in the direction of the leaning tree. Thus, it can minimize the risk of falling trees due to the load of the crown.

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