A safety factor of old trees *Pterocarpus indicus* Willd. in Bogor Botanic Gardens

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**Abstract.** Trees have a vital role in human life, including as a part of the urban forest area. The tree health assessment is an important activity to support tree safety and stability in an urban forest. Bogor Botanic Garden is the most extensive botanic garden in Indonesia, with a large collection. The study aims to determine the health condition of old trees (*Pterocarpus indicus* Willd.) in the Bogor Botanic Gardens and measure the safety factor's magnitude. The method used was an evaluation generated based on a sound velocity from Arborsonic's tool. The measurement of appearance parameters was carried out to complete the information in determining the biomechanical strength of the tree. Four large and old trees, about 170 years old, were chosen in this study. The results showed that decay to hollowness in the trunk varied from 4% to 58%. The biomechanical analysis calculates the safety factor and t/R ratio, revealing that one tree had moderate risk and others possessed low risk. Further investigation to ensure the tree condition should be carried in terms of risk mitigation of tree management.

1. **Introduction**

Bogor Botanic Gardens (BBG) is an ex-situ conservation area that serves an urban forest in Bogor, West Java. The urban forest is located at the center of the city, improving the quality of the urban environment [1]. Livesley and Calfapietra [2] said urban forests have four prominent roles: regulating a comfortable temperature for humans; hydrological systems; soil and water pollution; and air pollution regulation. Those four benefits are essential to resist various negative impacts that find in the urban environment. Managers and planners strive for appropriate forest designs and linkages, healthy trees, and long-term tree survival [3].

BBG is an urban forest that has become a mainstay tourist location in this city. These Botanic Gardens often become the central place to be visited by the local community. However, the risk of falling trees becomes a threat because fallen trees are a danger for visitors' safety in BBG. Some reasons that cause trees to fall are heavy rains, strong winds, physical conditions, and ecological processes [4, 5]. Therefore, it is essential to pay attention to tree health analysis in the Bogor Botanical Gardens. *Pterocarpus indicus* Willd. or locality named "Angsana" is a species commonly planted in Indonesia's urban forests and landscape. The plant has a natural distribution from Southeast Asia to the Pacific. In Indonesia, the natural distribution of Angsana is throughout Java, Sulawesi, Maluku, Bali, Nusa Tenggara, and Papua. Moreover, Angsana has many uses and high economic value, including furniture, agroforestry systems, shading trees for coffee plants, and potential as medicinal plants [6]. *P. indicus* gives shading and serves Pb absorber gases from the atmosphere [7]. This pioneer plant species
P. indicus in BBG as collection tree for conservation purposes. Based on the database, there are four old P. indicus planted in 1850 (more than 171 years old). Those collections trees are located in the high accessed area close to the main road. Knowing this tree's species risk is very important since it can fall because of age. The tree health status of P. indicus trees should be observed regularly related to tree management. This research aims to evaluate the tree health condition of old P. indicus Willd. in the BBG and measure the safety factor index.

2. Materials and Methods

2.1. Research location

This research was conducted in January-May 2021 at the Bogor Botanic Gardens with coordinates 106°47′40″–106°48′18″ east longitude and 6°35′32″–6°36′13″ south latitude in Bogor, West Java, Indonesia (figure 1). The altitude of the place is 257 m above sea level. The condition of the research site is clay textured, C-organic <2%, and total N 0.1–0.5% [9]. Determination of the sample using the purposive sampling method. The entire collection of the Pterocarpus genus in the Botanic Gardens is 23 trees aged 9-177 years. The samples taken were trees over 170 years old and located in primary areas (prone to visitors).

Figure 1. Location of Bogor Botanic Gardens
2.2. Research method

2.2.1. Measurement of the tree.
The measurements conducted in this study were tree height, tree diameter, crown diameter, LCR (leaf crown Ratio), crown area, slope, and aspect. The size of tree height and the crown length were carried out using a clinometer. The tip of the clinometer is placed in front of the eye (A). The other direction of the clinometer is pointed at the top of the object (E), the distance of point A to the corner pointer thread as point B. We measured the length from the base of the angle indicator thread as point C to point B. We measured the observer’s distance to the measured tree (FG) and the observer's height (AF). Then use the formula concept:

\[ \frac{CB}{AB} = \frac{DE}{AD} \Rightarrow DE = \frac{AD \times CB}{AB} \]

Object height \( EG = DE + AF \)

Measuring the tree diameter was carried out at the height of about 1.3 meters above the ground using diameter tape or roll meter. LCR was calculated based on the ratio of crown length divided by the total height of the tree. The crown diameter had measured by following the direction of the largest and smallest canopy width. This measurement is carried out using a rolling meter. The results from both directions of size were calculated to obtain the average width of the crown diameter. The slope is measured using a clinometer, then pointed to the slope of the location at the same high-level object. The slope will have an important influence on the drainage and the availability of light.

2.2.2. Measurement of Pterocarpus indicus tomography.
The method used in this research is the observation of the visual description of the Pterocarpus indicus tree. Then observations used Arborsonic® with a sound velocity analysis system, diameter tape, and clinometer. The 3D Acoustic Arborsonic® tomograph can detect the size and location of decayed or hollow sections in the Pterocarpus trunk non-destructively. The Arborsonic 3D Acoustic Tomograph principles place sensors around the trunk with steel nails, tapping each sensor with the hammer. The unit measures the travel time of the sound wave generated by hammer tapping each sensor; sound waves have to pass around the hole, and therefore it requires a longer time to reach the opposite sensors [10], as shown in figure 2.

![Figure 2. Principle of Arborsonic 3D Acoustic Tomography operation](image)

Observation of several physical parameters was carried out to determine the biomechanical strength of the tree through information from the Arborsonic 3D Acoustic Tomograph. Several measurement steps are conducted by choosing the measurement layer on the trunk, starting the software, and selecting the
tree species. They then placed the sensors (to the proper positions calculated by the software when using circle, elliptic or rectangular geometry). They registered the sensor geometry manually or with the Bluetooth Caliper (in case of irregular geometry). Collect time data by tapping on each sensor. Measurements at several layers are sometimes required. Choose the next layer and repeat the previous steps. They evaluated the cross-sectional maps, tomograms and performed stability computations (images made from the tree, including the whole canopy area, are also needed.). Calculating of biomechanics properties in software: using wind, crown type, and size, trunk parameter. Interpretation of displayed data – tree, layers, and details of the selected layer: wind load, drag factor, yield strength, tree weight above layer, safety factor, and risk rating [10]. Based on the equipment’s guideline, the percentage of safety factors as revealed from the tool is that safety factors <50% indicate an extreme level risk rating; 50-100% indicate high-level; 100-150% indicate moderate level, and >150% indicate low-level risk rating.

3. Results and Discussion

3.1. Physical description of Pterocarpus indicus

*Pterocarpus indicus* is a deciduous tree whose height can reach 30-40 meters, and the diameter can be up to 2 meters. The stem tends to twist and be deeply fluted, as well as the trees are often found with buttresses [11]. *P. indicus* is commonly planted as an urban forest in Indonesia which is found in many areas such as Bogor [12], Yogyakarta [7], Jakarta [13], Tangerang [14], dan Pekanbaru [15]. Bogor Botanic Gardens (BBG) has four species of *P. indicus*, which were planted in 1850. It indicates that the age of this tree has reached 171 years old. The condition of old trees is as follows in table 1 and has a greater risk of falling. Although visually, the *P. indicus* tree collection is in reasonably good condition.

![Figure 3. Pterocarpus indicus Willd collection: a. P02; b. P04](image)

*Figure 3. Pterocarpus indicus* Willd collection: a. P02; b. P04
### Table 1. Physical description of *Pterocarpus indicus* Willd collection tree in Bogor Botanic Gardens.

| No. | Code | Age (years) | Origin          | Height (m) | Tree Diameter (cm) | Crown Diameter (m) | LCR (%) | Crown area (m²) | Slope (°) | Aspect |
|-----|------|-------------|-----------------|------------|--------------------|--------------------|---------|-----------------|-----------|--------|
| 1   | P01  | 171         | Maluku: Ambon I.| 17.5       | 89.1               | 11.7               | 62.9    | 59.7           | 87        | NE     |
| 2   | P02  | 171         | Maluku: Ambon I.| 25.5       | 71.6               | 13.2               | 51.0    | 129.1          | 86        | SW     |
| 3   | P03  | 171         | Maluku          | 25.4       | 85.5               | 12.3               | 35.4    | 157.9          | 83        | NE     |
| 4   | P04  | 177         | S. Sulawesi     | 8.9        | 41.4               | 8.6                | 56.2    | 26.2           | 69        | NE     |

Table 1 showed that we observed the visual of *P. indicus* in BBG. All the trees are original from Maluku had height of 17.5 m; 25.4 m; 25.5 m; and diameter 71.6 cm; 85.5 cm; and 89.1 cm. In contrast, one of the *P. indicus* tree collections (P04) from South Sulawesi had 8.9 meters high and smaller in diameter, i.e., 41.4 cm. The measurement results of crown showed that live crown ratio (LCR) was not directly proportional to tree height and diameter. Competition between neighborhood trees for light and space plays a central role in shaping forest structure and dynamics [16, 17]. The wood formation and quality theory suggest that large crowns in a tree produce wood with inferior mechanical properties, negatively affecting the suitability of specific structural end-uses [18, 19]. Patterns of leaf shape and space in the canopy have an essential role in photosynthetic biomass and structural components to support mechanical water transport. The LCR of more than 60% was usually used as a reference in tree vigor in terms of crown coverage [20, 21, 22]. Trees with large LCR require a larger stem diameter that serves as support. The variation of LCR collection in each *P. indicus* is related to the space difference to grow in the area. The smallest LCR is owned by tree P03, which is in the second in height and diameter. The P02 and P03 trees had a larger diameter and canopy area than the two others. Meanwhile, P04 is the shortest tree with the smallest canopy compared to the other trees. All collections of old *P. indicus* have large dimensions so that in the event of a fall or collapse, it has a reasonably dangerous impact (figure 3).

#### 3.2. Decay of *Pterocarpus indicus*

Decaying on stems is difficult to detect visually, so it is essential to know the potential hazards in urban forests [23]. Checking the condition of the stem can be done by various methods, either destructively or non-destructively. The destructive method of drilling techniques is used to detect decay of stems by measuring resistance when drilling through the wood of different densities [24, 25, 26]. The method of nondestructive can use acoustic-based equipment which the result is figured in a tomography. Based on the tomogram results, our study found the decay conditions on *P. indicus* stems presented in table 2 and visualized in figure 4. The equipment can inform the percentage of tree decay. The worst decay till hollowness condition was shown in blue color in the tomogram. The higher the blue color area, the higher risk of the tree because of the existence of decay. The P01 and P04 were a tree with having high risk based on the percentage decay value. Meanwhile, P02 and P02 had low risk in decaying wood, as pointed out by the low percentage decay value (table 2) and appearance of green color in tomogram (figure 4).

### Table 2. Measurement results of *Pterocarpus indicus* Willd tomography.

| No. | Code | Layer 1 | Layer 2 |
|-----|------|---------|---------|
|     |      | Height (cm) | Diameter (cm) | Avg t/R | Decay (%) | Height (cm) | Diameter (cm) | Avg t/R | Decay (%) |
| 1   | P01  | 130     | 89.1    | 0.24    | 55        | 180       | 79.5      | 0.26    | 58       |
| 2   | P02  | 130     | 71.6    | 0.68    | 11        | 190       | 60.5      | 0.66    | 11       |
| 3   | P03  | 190     | 68.4    | 0.81    | 4         | 190       | 44.2      | 0.34    | 44       |
| 4   | P04  | 110     | 41.4    | 0.28    | 51        | 190       | 44.2      | 0.34    | 44       |
The results on the old *P. indicus* tree showed that there was decay in the main stem. The T/R ratio is simply the ratio of the sound wood shell thickness (T), without the bark, to the radius of the cross-section (R). If the value of the T/R ratio is less than 30 or 35%, it can be said to be dangerous [28]. Samples P01 and P04 had a 44-58% high decay percentage because almost half of the tree trunks had decayed (figure 4). T/R ratio thickness ratio is also categorized as small 24-34%. Based on the condition of the trunk, these trees can be classified as risk. It is different from the P02 tree sample, which shows that the decay in layers 1 and 2 is 11% with a T/R ratio of 0.66-0.68, so it is still categorized as safe. Tree health analysis using arborsonic has entirely accurate results. This method has been used in a previous study for *Agathis borneensis* species in Bogor Botanic Garden. The observations on *A. borneensis* showed great results illustrating actual conditions. Arborsonic observations show up to 75% decay with a predominantly light blue color [29]. After logging, the sample trees obtained substantial damage similar to the results analyzed (figure 5).
Figure 5. Visualization of Agathis borneensis stem analyzing by arborsonic compared with actual conditions after logging in Bogor Botanic Garden [29].

Tree morphology and description of stem damage are essential approaches to avoiding or delaying damage that causes trees to be said to be dangerous. This approach explores stem conditions and their mechanical expression with increasing size due to growth [30, 31]. The working stresses and stress capacities were used to quantify the safety factors of the stems of these trees [32]. The safety factor of trees is determined by cutting windows of well-defined size and shape into trees. The study calculated the related stress magnification factors compared to the unnotched solid trunk. As a result, trees can have at least 4-5 times higher stress in the stem without breakage [30].

Based on the Arborsonic 3D Acoustic Tomograph software guideline, the data should be input was a uniform wind model applied by a wind velocity of 33.0 m/s (the highest expected wind gust speed to reach the tree). A crown model uses an area calculator, i.e., by entering the center and bottom height. It should be input the trunk condition related to the degree and direction of lean. The drag factor (0.16) and yield strength (20 Mpa) were referred to based on the Fakopp database of the Fabaceae family. The safety factor formulation is yield stress divided by maximum stress. Yield strength is the yield strength of the trunk wood taken from the species database. Maximum stress is the maximal stress resulting from the torque and mass of the tree, taking into consideration the tomogram [10].

The running program in the equipment’s software shows that the P01, P03, and P04 have a low-risk index while P02 has a moderate risk index. Even though P02 had the lowest decay and the highest T/R ratio compared to other samples, the crown and tree height diameter was the largest. This safety factor index results from a software calculation to estimate the stress in the wood, and if this exceeds the maximum limit the material can resist, then the trunk would break. The calculated safety factor is the ratio of the wood strength from the species database as shown in yield strength. The calculated maximum stress, in general, is Safety factor = Yield Stress / Max Stress. The risk rating category is divided into four categories of safety factors, namely: extreme (below 50%), high (50-100%), moderate (100-150%), and low risk (above 150%) [10]. The safety factor is calculated to determine the mechanical load on a tree with an objective method to calculate the safety factor [32].

Table 3. Biomechanics analyzing the result of Pterocarpus indicus Willd tree.

| No. | Code | Wind Load (N) | Tree weight above layer (kg) | Safety Factor (%) | Risk rating |
|-----|------|---------------|-----------------------------|------------------|-------------|
| 1   | P01  | 7447          | 5630                        | 410              | Low risk    |
| 2   | P02  | 14881         | 4623                        | 123              | Moderate risk|
| 3   | P03  | 17804         | 5941                        | 171              | Low risk    |
| 4   | P04  | 3077          | 716                         | 332              | Low risk    |

Note: Arborsonic 3D Acoustic Tomography software calculation results
A tree can survive in its growing environment by relying on mechanical forces to overcome external factors like wind and bad weather. With increasing age, trees will experience an increase in size and increase the susceptibility of stems and roots to mechanical failure [32]. The moderate risk tree’s recommendation is to reduce the canopy load by pruning to reduce the risk rating. The second recommendation is making a signed notification and warning to visitors to be more careful around the tree. For the low-risk tree, the suggestion that we can give is periodic assessment for biomechanics analysis. Further investigation should be carried out mainly for the P01 and P04 since suspicious results must be clarified. The percentage decay results and the safety factor are opposite.

Tree maintenance management is essential to create and maintain a safe and beneficial urban forest for the community. Arborist needs training and expertise to recognize different levels of risk and manage urban forests at an acceptable level of risk. There have been many significant advances in detecting tree damage with tools, formulas, and guidelines for assessing tree damage. We can use these techniques to minimize the risk of tree damage and minimize the risk to humans [33].

4. Conclusion
This research concludes that the health of Pterocarpus indicus trees in Bogor Botanic Gardens is still safe based on safety factors. However, further investigation and periodic assessment should be carried out based on still higher decay percentage and lower t/R ratio, especially in trees of P01 and P04. The crown pruning and periodic inspections can be taken out to mitigate the risk from the tree.

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