NUSANTARA BIOSCIENCE
Vol. 17, No. 2, pp. 218-225
November 2025

ISSN: 2087-3948
E-ISSN: 2087-3956
DOI: 10.13057/nusbiosci/n170204

Morphological characterization and correlation of seed, fruit, and seedling of *Horsfieldia iryaghedhi*

INDRIANI EKASARI[1,♥], SAHROMI[2], PUTRI KESUMA WARDHANI[2]

[1]Research Center of Biota Systems, National Research and Innovation Agency. Jl. Raya Jakarta-Bogor Km. 46, KST Soekarno, Cibinong, Bogor 16911, West Java, Indonesia. Tel.: +62-21-87907604, ♥email: indriani.ekasari@brin.go.id

[2]Research Center of Applied Botany, National Research and Innovation Agency. Jl. Raya Jakarta-Bogor Km. 46, KST Soekarno, Cibinong, Bogor 16911, West Java, Indonesia

Manuscript received: 2 May 2025. Revision accepted: 4 September 2025.

Abstract. *Ekasari I, Sahromi, Wardhani PK. 2025. Morphological characterization and correlation of seed, fruit, and seedling of* Horsfieldia iryaghedhi. *Nusantara Bioscience 17: 218-225. Horsfieldia iryaghedhi* is a critically endangered species from the Myristicaceae family. Examining seed, fruit, and seedling morphology of the species is crucial, as generative propagation remains the only known conservation method. Therefore, this study aimed to determine the morphological characterization of the seed, fruit, and seedling of *H. iryaghedhi* and to analyse the correlation between seed, fruit, and seedling traits. This study was conducted at the Bogor Botanical Garden, utilizing five plant collections. The examined morphological traits included length, width, and weight of the seed, as well as fruit height, root collar diameter, and the number of leaves for the seedling. The results showed that the length, width, and weight of the fruit were 39.64±2.48 mm, 30.04±1.98 mm, and 20.33±3.60 g, respectively. Overall, the correlation between seed and fruit parameters indicates that one trait influences the other. The low variability in fruit and seed traits, despite being obtained from mother trees of different origins, has implications for the species' genetic diversity. The mean for seedling height is 106.74±32.78 cm, and the mean of collar diameter is 1.27±0.64 mm. Height and root collar diameter seedling traits were found to be closely related in 24-month-old seedlings. Understanding the ecology of seedling growth is essential for developing developmental strategies to conserve biodiversity and restore natural habitats. In conclusion, the variability in fruit and seed traits is exhibited by plants obtained from mother trees of different origins. The trees in the Bogor Botanical Gardens study site are mother trees, and this is extremely important for the future sustainable population of this species.

Keywords: Endangered species, Indonesia, Myristicaceae, plant traits, species conservation

INTRODUCTION

Horsfieldia iryaghedhi (Gaertn.) Warb. belongs to the Myristicaceae family and is frequently used for its medicinal properties in its native regions (Arrijani 2005; Waman et al. 2021). It is a woody tree species with a trunk ranging from 5 to 25 meters in height and up to 50 cm in diameter at breast height. The leaves are arranged alternately in two vertical rows, chartaceous, with petioles measuring between 1.5 and 3 cm in length; the blade shape ranges from ovate-elliptical to oblong-lanceolate, base rounded to attenuate, and apex acute to acuminate. The fruit is a one-seeded follicle, ellipsoid in shape, yellow-brown in color, and covered with dense, brown-yellow, stellate hairs; the pericarp thickness ranges from 1.5 to 3 mm. *H. iryaghedhi* flowers and bears fruit throughout the year, thriving in lowland rainforests, humid soils—sometimes with silt roots—wet evergreen forests, and disturbed forest ecosystems, from sea level up to an altitude of 500 meters (Wulijarni-Soetjipto 2001). This species is native to Sri Lanka (POWO 2024) and is widely distributed across South-east Asia, including Malaysia, Singapore, and Java.

The seed fat of *H. iryaghedhi* is used as an ingredient in candle production (van der Vossen 2001), while its flowers have been recognized as medicinal materials in Sri Lankan tradition since ancient times (Kankanamalage et al. 2014). Although several studies have investigated changes in species composition, stand structure, and geographical distribution, as well as phenotypic diversity and chemical composition across different habitats, only a few have explored the physiological responses of seeds, fruits, and seedlings. Given that *H. iryaghedhi* is either extinct in the wild or critically endangered (IUCN 2025), conservation efforts must prioritize protection within its native habitat, alongside ex-situ conservation measures such as botanical gardens.

Ex situ conservation involves relocating living plants or seeds from their native habitats to controlled environments to protect them from natural or human-induced threats (Zhao et al. 2022; Junaedi et al. 2023). Bogor Botanical Garden (BBG) is an ex-situ conservation area in Indonesia, maintaining over 12,370 accessions that encompass 3,555 species, 1,202 genera, and 191 families (Ariati et al. 2019). These collections are planted on an 87-hectare land area in the center of Bogor City, West Java Province, Indonesia. This Botanical Garden focuses on collections originating from Indonesia and abroad, and it conserves lowland humid and wet plant species (Wanda et al. 2022). Given the limited space available for expanding the BBG species collection, a planting strategy was implemented that allowed only a few trees of each species to be planted in the garden. These trees were chosen from the best growing seedlings, after which the origin of the seedlings or seeds was recorded, and their growth (including phenology) was frequently observed. This phenology helps restoration practitioners and endangered plant conservationists determine when to collect *H. iryaghedhi* fruits or seeds.

Many studies utilize morphological descriptors to differentiate among plant genetic resources (Poljak et al. 2021, 2024, 2025; Vidaković et al. 2024, 2025). Leaf morphometry is frequently employed to describe phenotypic diversity (Wanda et al. 2022; Puntieri and González 2023). However, in the context of this study, seeds and fruits hold even greater significance due to their essential role in plant conservation. Seed traits provide valuable insights for both taxonomic and functional differentiation. Beyond classification, seeds serve as the foundation of plant production (Drvodelić et al. 2025), food security (Yadav et al. 2024), ecological restoration (Leger et al. 2024), and the long-term persistence of sexually propagated species (Tumpa et al. 2021), as they directly influence germination success and seedling vigor. Seedling establishment, however, depends on a complex interplay of intrinsic seed attributes and environmental conditions (Sari et al. 2021; Nantongo et al. 2022). Among those attributes, seed mass is a reliable indicator of stored reserves available for early growth. Heavier seeds from the same mother tree and same species typically exhibit higher germination rates and produce more robust seedlings than lighter seeds, allowing them to withstand resource-limited environments and ultimately accelerate early growth (Nantongo et al. 2022).

Seedlings are a crucial component of plant populations, representing a vital stage in the life cycle of plants. The successful dispersal and maintenance of plant populations rely on seedling regeneration (Liu et al. 2019). Additionally, height-collar diameter correlations have been analyzed for gymnosperm and angiosperm trees and seedlings in China (Tumpa et al. 2021). Compared to mature trees, seedlings tend to exhibit greater height growth relative to stem diameter and possess higher height–diameter allometric exponents (Zhang et al. 2020).

This study aimed to characterize the morphological features of *H. iryaghedhi*'s seeds, fruits, and seedlings, as well as to analyze the correlations between seed, fruit, and seedling traits.

MATERIALS AND METHODS

Study area

This study was conducted between August and October 2023 at BBG in Indonesia (Figure 1). BBG is situated on 87 ha of land in the center of Bogor City, West Java, Indonesia (6°35'51.46"S, 106°47'58.45"E), at an altitude of 230-270 m above sea level. Bogor has a tropical climate, with an average temperature ranging from 25-27.4°C, an average humidity of 80%, and an annual rainfall of 3.658 mm/year (Safarinanugraha et al. 2018; Wanda et al. 2022), and the soil type is primary Latosol (a type of soil formed from weathered volcanic rock).

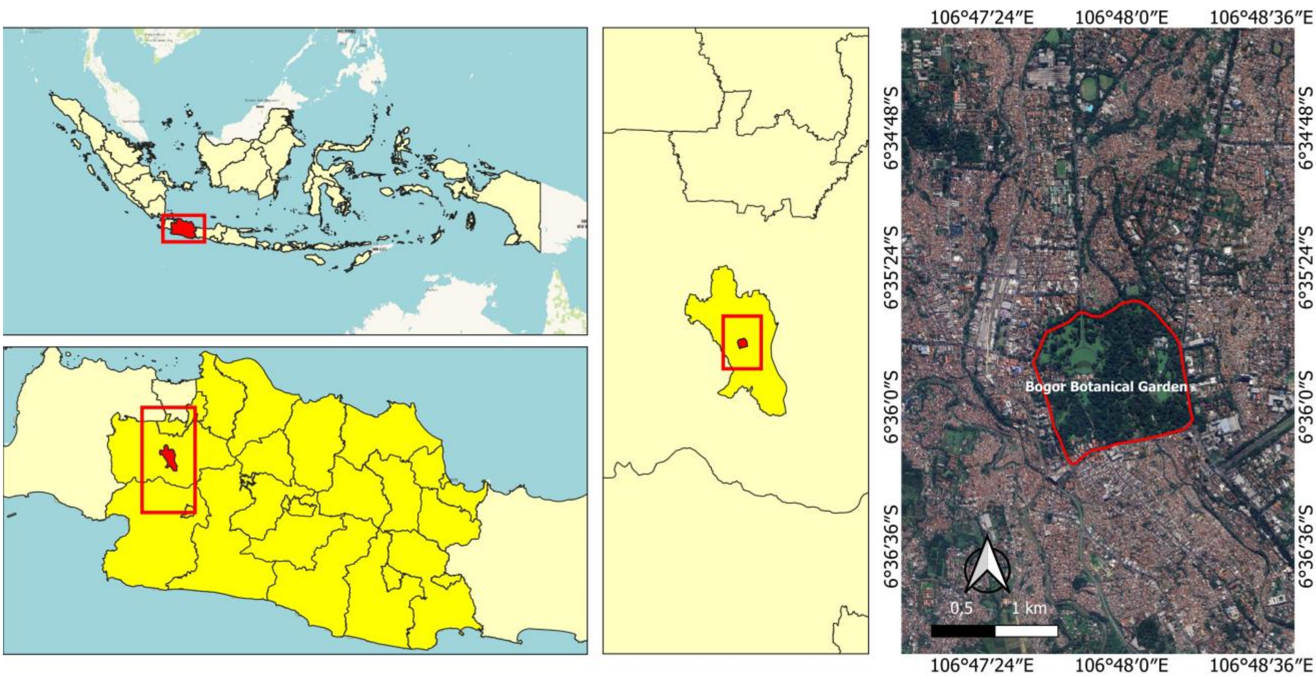

Figure 1. Study site of *Horsfieldia iryaghedhi* in Bogor Botanical Garden, Bogor City, West Java, Indonesia

Plant materials

The BBG conserved nine *Horsfieldia iryaghedhi* trees, eight from Sri Lanka and one from Papua (Ariati et al. 2019). Of these, only five trees were mature and fruiting during the study, all of which originated from Sri Lanka. Tree height (m), diameter at breast height (DBH, cm), and botanical location of each numbered tree were recorded and used in the selection process. Height, DBH, and crown diameter were measured using a hypsometer and diameter tape, respectively (Table 1). Ultimately, five trees were sampled for fruit collection at the site. The selected trees showed no signs of pests or disease, had straight, circular stems with large diameters, fine horizontal branches, and produced an abundance of fruit.

According to phenology data from the BBG registration department, in previous years, *H. iryaghedhi* flowered from January to July, producing mature fruit. By August, when this study was conducted, the availability of mature fruit had declined, leaving only 27 viable samples for testing. In comparison to other *Horsfieldia* species, the ripened seeds of *H. kingii* in north-east India are available from February to April (Datta and Rane 2013). In contrast, those of *Horsfieldia hainanensis* in Yunnan Province, China, are available from April to May (Liu et al. 2024). These fruit samples were carefully selected and randomly collected. To prevent heat exposure and maintain freshness, the collected fruit was stored in cloth bags. The seeds were then transported to the laboratory on the same day for further processing. After selecting mature fruit from the twigs, a cutting test was performed to assess freshness, with selected fruit characterized by yellow-brownish peels.

Data collection

A total of 27 fruits of *H. iryaghedhi* were measured for three major morphological traits, including weight, length, and width (diameter). Seeds were collected from the peeled fruits, and then their length and width were measured using a digital caliper, while their weight was determined with a digital scale. The single-seed weight was measured using a precision balance with an accuracy of 0.01 g.

In addition to observing the physical properties of fruits and seeds, this study also observed 24-month-old *H. iryaghedhi* seedlings grown under uniform nursery conditions with no shade. These seedlings were planted in similar soil environments, maintaining consistent growth vigor and canopy structure. A total of 52 seedlings were evaluated for height, basal diameter, and leaf count. Seedling height was measured to the nearest millimeter using a ruler, basal diameter was recorded with digital calipers, and collar diameter was measured to the nearest 0.1 mm using a digital caliper.

Data analysis

Descriptive, correlation, and regression analyses were performed using MS Excel for Windows 11. Regression analyses were performed to observe the correlation between all treatments concerning seed, fruit, and seedling performance parameters.

RESULTS AND DISCUSSION

A total of five *Horsfieldia iryaghedhi* trees, each over 40 years old, were measured for this study. The height of these trees ranged from 8 to 23.9 m, while their diameter at breast height varied from 52.23 to 184.08 m. The crown diameter spanned from 5.2 to 8.9 m (Table 1). The mean wind velocity and air temperature recorded were 1.68±0.27 m/s and 34±1.34ºC, respectively. These trees were planted along the edge of the lake in the BBG, mirroring their natural habitat within the wet tropical biome (POWO 2024).

Variability of seeds, fruits, and seedlings of *Horsfieldia iryaghedhi*

All morphological traits of seeds (length, width, and weight), fruits (length, width, and weight), and seedlings (height, root collar diameter, and number of leaves) were examined to ensure standard parametric test assumptions were met before analysis. Detecting seed size can impact production, breeding, storage, and transportation, while also enhancing quality (Yin et al. 2023). Seed weight in this study ranged from 2.90 g to 8.80 g, with a mean of 5.57±1.27 g (Table 2). The mean seed length and diameter were 28.17±2.08 mm and 19.37±2.23 mm, respectively. In general, larger seeds result in heavier seedlings with more resources being dedicated to seedling development (Nantongo et al. 2022). Therefore, this study recommends that heavier seeds will have a better germination rate and produce more vigorous seedlings than lighter ones. This also improves seedling survival up to the period of leaf growth, reducing reliance on seed stores (Naruangsri et al. 2023; Barczyk et al. 2024) for photosynthesis.

Table 1. Characteristics of *Horsfieldia iryaghedhi* trees sampled for fruit and seed collection in Bogor Botanical Garden, Indonesia

Location in the garden	Height (m)	Diameter breast height (cm)	Crown diameter (m)	Wind velocity (m/s)	Temp (ºC)	Air humidity (%)
IV. G. 155	23.9	26.11	7.7	1.2	32.8	42
XIII. F. 6	8.0	24.84	5.2	1.8	33.7	46
XIII. 9 (o)	15.9	92.04	8.9	1.8	34.5	45
XIII. 11	11.5	48.73	7.9	1.8	33	43
XIII. 11 a	11.5	35.67	6.6	1.8	36	41
Mean	14.16	45.47	7.26	1.68	34	43.4
SD	6.12	27.72	1.41	0.27	1.30	2.07
CV	0.43	0.61	0.19	0.16	0.04	0.05

Note: SD: Standard deviation; CV: Coefficient of variation

Under optimal conditions, resources are primarily allocated to plant growth and the production of large seeds to store more nutrients, thereby enhancing the seedling's ability to respond to adverse conditions. Seed size, a functional trait, has implications for seedling germination, survival, and recruitment. According to reports, seedlings developed from large seeds tend to exhibit a higher growth capacity (Martínez-González et al. 2021).

The length, diameter, and weight of mature fruit ranged from 32.80 to 43.60 mm, 24.60 to 33.90 mm, and 10.90 to 26.10 g, respectively, with mean values of 39.64±2.48 mm, 30.04±1.98 mm, and 20.33±3.60 g. According to Martínez-González et al. (2021), seeds serve as the fundamental propagation unit for the majority of trees. Variability in seed and fruit size can be primarily attributed to genetic diversity within the sample population. Morphological variability in plants is a crucial mechanism that enables species to adapt to their immediate environment. Plant populations often occupy large areas, continuous or disjoint, in which the pressures on individuals can differ significantly. Under such conditions, different populations and individuals can exhibit considerable variation in phenotypic and genetic diversity (Vidaković et al. 2024). However, the location of fruit on the tree, as well as differing microclimatic conditions within the canopy and soil, can also contribute to variability in fruit development within the same tree. Seeds, as a generative propagation material, are essential to understanding their variability in conservation strategy for *H. iryaghedhi*. This study found low variability in fruits and seeds collected from five mother trees of *H. iryaghedhi* in the BBG, despite the mother trees originating from different locations (Papua and Sri Lanka). *H. iryaghedhi* planted in the BBG did not exhibit any differences in terms of height, breast-height diameter, or crown diameter due to any environmental conditions. The low CV (CV<1) suggested that there was essentially no difference in growth across the five mother trees (Table 1).

The lowest seedling height recorded was 82.60 cm, while the highest reached 143.70 cm. The overall mean values for seedling height, collar diameter, and number of leaves were 106.74±32.78 cm, 1.27±0.64 mm, and 17.54±12.23, respectively. Certain seedling traits, particularly those related to conservation (e.g., biomass) and resource acquisition (e.g., foliar area), play a crucial role in life-cycle strategies. These traits may exhibit similarities across both tropical rainforests and tropical dry forests. Limited information on the percentage of *H. iryaghedhi* seed germination necessitates conservation issues for this genus. However, seedling management in the nursery until the appropriate planting period is critical. According to a previous study, *Horsfieldia hainanensis* has a successful regeneration rate of 0.4-5.6% in its natural habitat between the ages of 0 and 4 years, due to pathogen and herbivore attacks (Liu et al. 2019). This implies that seedling maintenance in the nursery is necessary to preserve this species. Seedlings taller than 200 cm have reasonably good survival prospects because they escape ungulate browsing at this height (Waller et al. 2020).

This study found that all seeds and fruits used in the experiment exhibited a proportionate oval form. A shorter diameter and a longer length characterized the overall shape of the seeds and fruits. Seed and fruit weight correlated with the weight of ripe fruit, including the seed, peel, and flesh. Shape is an essential factor in many respects (Drvodelić et al. 2025), and when *H. iryaghedhi* fruit can be domesticated, it will be more appealing to customers. According to previous research, seeds of the Myristicaceae family, including *H. iryaghedhi*, are relatively large (Arrijani 2005). The mean seeds found in this study were comparatively bigger when compared to those of *H. glabra* (Waman et al. 2021), with a seed length of 27.4 cm, a seed width of 16.2 cm, and a seed weight of 3.7 g, and *H. hainanensis* (Liu et al. 2024) with a seed weight of 5-6 g. Seedling growth may be hindered if seeds are uniform in size and shape. Moreover, seed size has a significant impact on growth traits, with seedlings from larger seeds generally exhibiting superior performance in terms of height, biomass, leaf number, and foliar area (Martínez-González et al. 2021). For ecological purposes, the fruit and seed of *H. iryaghedhi* are relatively large and heavy, meaning their natural distribution tends to be close to the parent tree. Consequently, when the species is introduced to the natural environment, human intervention may be required to facilitate dispersal (Ekasari et al. 2025).

Correlation between seed and fruit parameters (length, width, and weight)

The correlation between seed length, width, and weight is presented in Table 3. A positive correlation was observed among these parameters, with the lowest significant positive correlation found for the seed length parameter, which is the correlation between seed width and seed length (r=0.52, p<0.001) within the medium category. In addition, the highest positive correlation for the seed length parameter was observed between seed length and fruit weight (r=0.83, p<0.001), which falls within the very strong category. It is suggested that the seed length increases with the fruit weight. This study demonstrates that seed length parameters are linearly correlated with other seed and fruit parameters. The strong correlation indicates that commonly measured seed traits—length, width, and weight—have a genetic basis (Dicko et al. 2019).

Among all parameter associations, fruit weight and length exhibited the strongest correlation (r=0.88, p<0.001). The analysis of 27 seeds revealed correlations ranging from medium to very strong, except the low correlation between fruit width and seed width (r=0.27, p<0.001). The findings of this study suggest that the width of *H. iryaghedhi* seeds is not linearly related to fruit width, but is linearly related to the other parameters in the seeds and fruit. Furthermore, this study suggests that the morphological traits of the analyzed seeds can be used to predict one parameter based on another, opening up new possibilities for predictive plant morphology. Fruit and seed morphological traits are highly correlated, suggesting that factors affecting fruit also influence seed proportionally. A previous study demonstrated a positive and significant correlation between the fruit weight, length, and width of *Entandrophragma bussei* in Tanzania (Andrew et al. 2021).

Correlation between seedling parameters (height, collar diameter, and number of leaves)

The seedling parameters showed a medium correlation with height (r=0.42, p<0.001) and root collar diameter parameters (r=0.51, p<0.001). Only the correlation for root collar diameter and height parameters was strong (r=0.76, p 0.001). This study suggests that the two parameters (seedling height and root collar diameter) have a strong correlation for 24-month-old seedlings of *H. iryaghedhi* at the BBG nursery (Table 7). Many countries apply morphological attributes to evaluate seedling quality, including height and root collar diameter. Seedling age is one of the primary quantitative morphological attributes (Mataruga et al. 2023; Naruangsri et al. 2023). The height tends to increase faster than the root collar diameter at the seedling stage, with growth standards varying depending on the container size in the nursery (Zhang et al. 2020; Mataruga et al. 2023).

The number of leaves parameter has a medium correlation with seedling height and root collar diameter. This result implies that the condition of 24-month-old *H. iryaghedhi* seedlings was defined by seedling height and root collar diameter, having a medium correlation with the number of leaves surviving and growing in the nursery. Tree species may optimize growth strategies in response to environmental conditions by reducing the risk of bending or falling while also maximizing efficiency in using the most limited resources (Zhang et al. 2020), such as limited root growth space due to polybags or containers, or competition for sunlight. Furthermore, plants allocate a higher proportion of biomass to leaves and a larger root collar diameter in nutrient-rich environments where above-ground competition for light is intense. In nutrient-poor environments, where below-ground competition prevails, plants allocate a higher proportion of their resources to roots (Nantongo et al. 2022).

Root collar diameter parameter is influential for the survival of *H. iryaghedhi* species groups and has proven to be more indicative than the height parameter. This trait may serve as a better indicator of energy reserves for the seedling during its next growth phase. It is also typically more closely correlated to both total and below-ground seedling biomass. Aside from seedling height, root collar diameter is another good predictor of future plantation success (Bayala et al. 2009; Jones et al. 2023).

Survival often varies among sites and seedlings of different sizes, as growth is notoriously responsive to local conditions. It frequently takes time to progress through vulnerable-size classes, which can be either short-term or long-term (Waller et al. 2024). The strong correlation between height and root collar diameter parameters (r=0.76, p<0.001) in 24-month-old *H. iryaghedhi* seedlings highlights differences in seedling development and survival. Meanwhile, a previous study found that the growth of seedling height was directly related to the number of leaves but inversely proportional to the increase in root collar diameter (Nantongo et al. 2022). Examining differences in seedling development and survival will help determine the trait with limited regeneration parameters.

Table 2. Distribution of seed, fruit, and seedling of *Horsfieldia iryaghedhi* collection of Bogor Botanical Garden, Indonesia

Parameters	Minimum	Maximum	Mean	SD	CV (%)
Seed length (mm)	23.10	31.10	28.17	2.08	0.07
Seed diameter (mm)	16.40	29.10	19.37	2.23	0.11
Seed weight (g)	2.90	8.80	5.57	1.27	0.23
Fruit length (mm)	32.80	43.60	39.54	2.48	0.06
Fruit diameter (mm)	24.60	33.90	30.04	1.98	0.06
Fruit weight (g)	10.90	26.10	20.33	3.60	0.18
Seedling height (cm)	82.60	143.70	106.74	32.78	0.31
Root collar diameter (mm)	0.73	1.88	1.27	0.64	0.51
Number of leaves	7.00	36.00	17.54	12.23	0.71

Note: SD: Standard deviation; CV: Coefficient of variation

Table 3. The correlation coefficient between the length, width, and weight of fruit and seed parameters of *Horsfieldia iryaghedhi*

Parameters	Seed length	Seed width	Seed weight	Fruit length	Fruit width	Fruit weight
Seed length	1	***	***	***	***	***
Seed width	0.52	1	***	***	ns	***
Seed weight	0.74	0.59	1	***	***	***
Fruit length	0.81	0.56	0.55	1	***	***
Fruit width	0.65	0.27	0.40	0.67	1	***
Fruit weight	0.83	0.50	0.53	0.88	0.83	1

Note: 0.000-0.199: Very low, 0.200-0.399: Low, 0.40-0.599: Medium, 0.600-0.799: Strong, 0.800-1.000: Very strong. Source: (Sugiyono 2010). ***: p>0.001, ns: non-significant

Table 4. Correlation between height, root collar diameter, and number of leaves on seedling parameters of *Horsfieldia iryaghedhi*

Seedling parameters	Height	Collar diameter	Number of leaves
Height	1	***	***
Root collar diameter	0.76	1	***
Number of leaves	0.42	0.51	1

Note: 0.000-0.199: Very low, 0.200-0.399: Low, 0.40-0.599: Medium, 0.600-0.799: Strong, 0.800-1.000: Very strong. Source: (Sugiyono 2010). ***: p>0.001, ns: non-significant

Understanding the ecology of seedling growth is essential not only for gaining knowledge about plant community processes and succession, but also for developing strategies to conserve biodiversity and restore natural habitats (Susanto et al. 2016). Therefore, seedlings need to be monitored in the field, as environmental traits that are suitable for seed germination may not be ideal for seedling or adult plant development, which generates a conflict between seed and seedling development (Nantongo et al. 2022).

Conservation efforts and their implications in this study

The species *H. iryaghedhi* remains largely unknown, particularly in Indonesia, and is currently classified as a garden collection at the BBG in West Java and the Purwodadi Botanical Garden (PBG) in East Java (Junaedi et al. 2023). Its utilization has received minimal attention. Given that this species is critically endangered and possesses medicinal properties, it is essential to implement appropriate conservation strategies, such as planting it as a collection plant in botanical gardens. Currently, generative propagation via seed is the only known method for conserving the Myristicaceae family, with limited research on vegetative propagation. Since this species is classed as severely endangered, effective genetic conservation measures must be considered in the future, such as seed conservation starting from determining the seed collection protocol, seed sorting, seed testing, seed germination, intensive care in the nursery, and the reintroduction protocol if this species is replanted into its natural habitat.

This study found a strong correlation between the fruit and seed traits of *H. iryaghedhi*; therefore, seed conservation should begin with selecting healthy and normal-sized fruits to obtain seeds of similar size (normal size). Twenty-four-month-old seedlings in the BBG nursery are not yet ready to be planted in their natural habitat, as they have a mean height of 106±32.74 cm, which is less than 2 m. Seedlings with above 2 m are thought to be more resistant to the underpressure of sunlight, have bigger roots to get nutrients, and are pathogen-resistant. Another case for *H. kingii* is that low tree densities, sporadic and supra-annual fruiting, skewed sex ratios, and possible pollination limitations may result in low fruit and seed availability for this species, as well as the effects of anthropogenic disturbances, deforestation, and climate change, placing them at greater risk in their natural habitat (Datta and Rane 2013).

This study was limited to one fruiting year, and there is no previous literature on the morphology of *H. iryaghedhi* fruits collected from BBG and PBG. Future studies could investigate whether changes in seed morphology occur from year to year, influenced by environmental conditions and fruit position on the tree, allowing for additional multivariate analysis, such as principal component analysis (PCA) or other cluster analysis. In addition to being a collection plant at BBG, the *H. iryaghedhi* collection planted in PBG in East Java can be explored further if used as genetic material, given that the two sites present different conditions. This highlights the need for a comprehensive conservation approach, including intensive phenological studies from the flowering stage to the fruit maturation. Selecting fruit and seeds with proportional shape and larger size from the same population will enhance quality and promote future growth (Martínez-González et al. 2021). Although this study was constrained by the limited number of seeds and trees analyzed, it provides valuable insights into the morphology and characteristics of seeds, fruits, and seedlings, which can be easily altered for future research or practical field applications. Collaboration between nursery practitioners and field managers is essential to identify plant traits that support the survival of *H. iryaghedhi* seedlings. Practitioners should also provide nursery workers with additional insights on habitat conditions and contribute observations regarding reforestation efforts and the success of different seedling varieties. This is crucial for producers to enhance seed quality, taking into account the findings and recommendations (Mataruga et al. 2023).

In conclusion, *H. iryaghedhi*'s seed and fruit traits were predicted using length, width, and weight parameters, revealing a positive correlation among all tested traits. All traits examined at BBG showed low variability despite being obtained from mother trees from different origins. Additionally, height and root collar diameter traits were found to be closely related in 24-month-old seedlings, with the root collar diameter increasing with seedling height. However, only a minimal correlation was found between the number of leaves and either seedling height or root collar diameter. Given that *H. iryaghedhi* is critically endangered, further efforts are necessary to enhance both in situ and ex-situ conservation strategies. The BBG is an important site that serves as a source of propagation material for growing new seedlings and transplanting them to similar sites within the BBG. It is essential to understand that the trees in BBG are mother trees, and this is extremely important for the future population of this species, as they would be one of the primary sources of seeds for *H. iryaghedhi*.

ACKNOWLEDGEMENTS

The authors are grateful to the Director of the Research Center for Plant Conservation, Botanic Gardens and Forestry-BRIN (National Research and Innovation Agency-Republic of Indonesia), for supporting this study, as well as to Erica Tira Mutia and Novita Dyah Wulandari for their assistance with data sampling. The author contributions are as follows: Indriani Ekasari: conceptualization, data analysis, visualization, and manuscript improvement; Sahromi: conceptualization, data collection, and manuscript revision; Putri Kesuma Wardhani: review and editing. This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors declare no conflict of interest regarding the publication of this article.

REFERENCES

Andrew SM, Kombo SA, Chamshama SAO. 2021. Diversity in fruit and seed morphology of wooden banana (*Entandrophragma bussei* Harms ex Engl.) populations in Tanzania. Tree For People 5: 100095. DOI: 10.1016/j.tfp.2021.100095.

Ariati SR, Astuti RS, Supriyatna I, Yuswandi AY, Setiawan A, Saftaningsih D, Pribadi DO. 2019. An Alphabetical List of Plant Species Cultivated in The Bogor Botanic Gardens, Bogor: Center for Plant Conservation Botanic Gardens. Indonesian Institute of Sciences, Bogor, Indonesia.

Arrijani A. 2005. Review: Biology and conservation of genus *Myristica* in Indonesia. Biodiversitas 6: 147-151. DOI: 10.13057/biodiv/d060216.

Barczyk MK, Acosta-Rojas DC, Espinosa CI, Schleuning M, Neuschulz EL. 2024. Seedling recruitment of small-seeded and large-seeded species in forests and pastures in southern Ecuador. Basic Appl Ecol 75: 44-52. DOI: 10.1016/j.baae.2024.01.005.

Bayala J, Dianda M, Wilson J, Ouédraogo SJ, Sanon K. 2009. Predicting field performance of five irrigated tree species using seedling quality assessment in Burkina Faso, West Africa. New For 38 (3): 309-322. DOI: 10.1007/s11056-009-9149-4.

Datta A, Rane A. 2013. Phenology, seed dispersal and regeneration patterns of *Horsfieldia kingii*, a rare wild nutmeg. Trop Conserv Sci 6 (5): 674-689. DOI: 10.1177/194008291300600507.

Dicko A, Natta AK, Biaou HSS, Akossou A. 2019. Assessing morphological traits variation and fruit production of *Lophira lanceolata* (Ochnaceae) in Benin. Am J Plant Sci 10 (6): 1048-1060. DOI: 10.4236/ajps.2019.106076.

Drvodelić D, Španjol E, Vuković M, i Jemrić T. 2025. Medlar (*Mespilus germanica* L.) fruit morphology depending on fruit size. Šumarski List 149 (3-4): 115-126. DOI: 10.31298/sl.149.3-4.1.

Ekasari I, Lailati M, Nurlaeni Y, Puspanti A, Mufida YR. 2025. Seed morphology and seedling growth modeling for *Litsea cordata* and *Sloanea sigun* in Java montane forests. Intl J Des Nat Ecodynamics 20 (3): 547-554. DOI: 10.18280/ijdne.200310.

IUCN. 2025. https://iucnredlist.org.

Jones PD, Sabo AE, Forrester JA, Mladenoff DJ, McDill ME. 2023. Northern hardwood seedlings respond to a complex of environmental factors when deer herbivory is limited. For Ecol Manag 527: 120600. DOI: 10.1016/j.foreco.2022.120600.

Junaedi DI, Nasution T, Putri DM, Iryadi R, Lestari R, Kurniawan V, Pratiwi RA, Handayani A, Sudarmono. 2023. Threatened exotic species of botanical gardens: Application of trait-based naturalized species risk scoring assessment. S Afr J Bot 152: 321-331. DOI: 10.1016/j.sajb.2022.11.046.

Kankanamalage TNM, Dharmadasa RM, Abeysinghe DC, Wijesekara RGS. 2014. A survey on medicinal materials used in traditional systems of medicine in Sri Lanka. J Ethnopharmacol 155 (1): 679-691. DOI: 10.1016/j.jep.2014.06.016.

Leger E, Agneray A, Baughman O, Brummer E, Erickson T, Hufford K, Kettenring K. 2024. Integrating evolutionary potential and ecological function into agricultural seed production to meet demands for the decade of restoration. Restor Ecol 32 (8): e13543. DOI: 10.1111/rec.13543.

Liu X, He Y, Xiao Y, Wang Y, Jiang Y, Jiang Y. 2019. Soil seed burial and competition with surrounding plants determine the emergence and development of seedling of the endangered species *Horsfieldia hainanensis* Merr. in China. Sci Rep 9: 17970. DOI: 10.1038/s41598-019-54644-7.

Martínez-González I, Velázquez-Rosas N, Pineda-López MdelR, Ruiz-Guerra B, Sánchez-Velásquez LR. 2021. The role of seed size in the performance of *Ceiba aesculifolia* seedling subjected to foliar damage. Acta Oecol 112: 103772. DOI: 10.1016/j.actao.2021.103772.

Mataruga M, Cvjetković B, De Cuyper B et al. 2023. Monitoring and control of forest seedling quality in Europe. For Ecol Manag 546: 121308. DOI: 10.1016/j.foreco.2023.121308.

Nantongo JS, Mudondo S, Oluk R, Agaba H, Gwali S. 2022. Variation in seed and seedling traits of the different ethno-varieties of jackfruit, a potential fruit tree species for food security. Tree For People 9: 100303. DOI: 10.1016/j.tfp.2022.100303.

Naruangsri K, Tiansawat P, Elliott S. 2023. Differential seed removal, germination and seedling growth as determinants of species suitability for forest restoration by direct seeding - A case study from northern Thailand. For Ecosyst 10: 100133. DOI: 10.1016/j.fecs.2023.100133.

Poljak I, Šatović Z, Vidaković A, Tumpa K, Idžojtić M. 2024. Population variability of rosemary willow (*Salix eleagnos* Scop.) based on leaf morphometry: Evidence of small and large-leaf morphotypes. Šumarski List 148 (5-6): 219-236. DOI: 10.31298/sl.148.5-6.1.

Poljak I, Tumpa K, Vidaković A, Šatović Z, Liber Z, Jezic M, Ćurković-Perica M, Idžojtić M. 2025. Morphological variability of fruits and leaves allows delimitation between cultivated and wild chestnuts and their natural crosses. Genet Resour Crop Evol 72 (4): 3953-3968. DOI: 10.1007/s10722-024-02195-w.

Poljak I, Vahčić N, Vidaković A, Tumpa K, Žarković I, Idžojtić M. 2021. Traditional sweet chestnut and hybrid varieties: Chemical composition, morphometric and qualitative nut characteristics. Agronomy 11 (3): 516. DOI: 10.3390/agronomy11030516.

POWO [Plants of The World Online]. 2024. Plants of The World Online. Royal Botanic Gardens Kew. www.powo.kew.org.

Puntieri J, González AM. 2023. Are the anatomical traits of stems and leaves good indicators of habitat specificity in closely related Myrtaceae species from Patagonia? Acta Bot Bras 37: e20230019. DOI: 10.1590/1677-941X-ABB-2023-0019.

Safarinanugraha D. Gunawan A. Mugnisjah WQ. 2018. The development of Bogor Botanic Garden design from 1817 to 2017 base on spatial and functional. IOP Conf Ser: Earth Environ Sci 179 (1): 012026. DOI: 10.1088/1755-1315/179/1/012026.

Sari N, Silverman E, Reiland D, Wehner TC. 2021. Seed characterization and correlations between seed and cotyledon properties in *Lagenaria* spp. Accessions. HortScience 56 (2): 185-192. DOI: 10.21273/HORTSCI15569-20.

Sugiyono. 2010. Metode Penelitian Kuantitatif, Kualitatif, dan R&D [Quantitative, Qualitative Research Methods, and Research and Development]. Alfabet, Bandung, Indonesia.

Susanto D, Ruchiyat D, Sutisna M, Amirta R. 2016. Flowering, fruiting, seed germination and seedling growth of *Macaranga gigantea*. Biodiversitas 17 (1): 192-199. DOI: 10.13057/biodiv/d170128.

Tumpa K, Vidaković A, Drvodelić D, Šango M, Idžojtić M, Perković I, Poljak I. 2021. The effect of seed size on germination and seedling growth in sweet chestnut (*Castanea sativa* mill.). Forests 12 (7): 858. DOI: 10.3390/f12070858.

van der Vossen HUB. 2001. Plant Resources of South-East Asia 14: Vegetables Oil and Fat. Backhuys, Leiden.

Vidaković A, Benić L, Mrvičić I, Pešut E, Jakšić V, Poljak I. 2024. Morphological variation in blackthorn (*Prunus spinosa* L.) populations in the Northwestern part of the Balkan Peninsula - Absence of geographical and environmental structure. Acta Soc Bot Pol 93: 187157. DOI: 10.5586/asbp/187157.

Vidaković A, Radunić M, Poljak I. 2025. Variation in chemical composition and fruit morphometric traits of almond-leaved pear (*Pyrus spinosa* Forssk.) natural populations. Genet Resour Crop Evol 72: 1495-1510. DOI: 10.1007/s10722-024-02059-3.

Waller DM, Riege DA, Alverson WS. 2024. The regeneration ratio: Combining seedling growth and mortality data to predict regeneration success. For Ecol Manag 556: 121737. DOI: 10.1016/j.foreco.2024.121737.

Waman AA, Bohra P, Roy TK, Shivashankara KS. 2021. Seed morphological and biochemical studies in certain wild nutmegs. Trees 35 (3): 939-945. DOI: 10.1007/s00468-021-02091-1.

Wanda IF, Rachmadiyanto AN, Oksari AA. 2022. Leaf morphometric and chlorophyll content study of bisbul (*Diospyros discolor* Willd.) at the Bogor Botanical Garden. J Trop Biodivers Biotechnol 7 (2): jtbb72565. DOI: 10.22146/jtbb.72565.

Wulijarni-Soetjipto NJPCM. 2001. *Horsfieldia iryaghedhi* (Gaertn.) Warb. In: van der Vossen HAM, Umali BE (eds). Plant Resources of South-East Asia No 14: Vegetable oils and fats. PROSEA Foundation, Bogor, Indonesia.

Yadav A, Garg S, Kumar S, Alam B, Arunachalam A. 2024. A review on genetic resources, breeding status and strategies of dragon fruit. Genet Resour Crop Evol 72 (3): 2511-2531. DOI: 10.1007/s10722-024-02123-y.

Yin H, Xie B, Chen B, Ma J, Chen J, Zhou Y, Han X, Xiong Z, Yu Z, Huang F. 2023. Detection of moisture content and size of pumpkin seed based on hyperspectral reflection and transmission imaging techniques. J Food Compost Anal 124: 105651. DOI: 10.1016/j.jfca.2023.105651.

Zhang WP, Zhao L, Larjavaara M, Morris EC, Sterck FJ, Wang GX. 2020. Height-diameter allometric correlations for seedling and trees across China. Acta Oecol. 108: 103621. DOI: 10.1016/j.actao.2020.103621.

Zhao X, Chen H, Wu J, Ren H, Wei J, Ye P, Si Q. 2022. Ex-situ conservation of threatened higher plants in Chinese botanical gardens. Glob Ecol Conserv 38: e02206. DOI: 10.1016/gecco.2022.e02206.