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MORALITY BEFORE KNOWLEDGE

A systematic review of the current botany, phytochemical, pharmacological, and conservation status of the Macassar ebony (*Diospyros celebica* Bakh.)

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ABSTRACT

Background: *Diospyros celebica*, commonly known as Macassar ebony, is a tree species endemic to Sulawesi with high economic value that is currently experiencing a significant decline in its population. This decline is primarily caused by illegal harvesting and logging, which threaten the species' survival in its natural habitat. **Methods**: This study conducted a systematic review of the literature, gathering data from Google Scholar and Scopus. The analysis focused on botanical and ecological characteristics, pharmacological bioactive compounds, and conservation efforts. **Findings**: *Diospyros celebica* exhibits morphological features such as reaching up to 40 meters in height, a trunk diameter of up to 100 centimeters, a cylindrical shape, and fine wood fibers. The branching pattern is continuous, with horizontal branch growth. The leaves are simple, with an alternating arrangement and semi-terete petioles along the edges. Pharmacologically, its bioactive compounds show promise for treating infections and various diseases. The IUCN Red List classifies ebony as Vulnerable. The main challenge to conservation is its very slow growth rate. Recommended strategies include enhancing in-situ and ex-situ conservation, optimizing tissue culture techniques for mass propagation, and using microbes to accelerate seedling growth. **Conclusion**: Beyond its economic importance, ebony contains significant compounds, such as flavonoids, that function as antidiabetic agents. As an endemic species, *D. celebica* plays a vital ecological role as a carbon sink, helping maintain the stability of tropical forest vegetation. Its preservation is crucial due to threats like breeding depression caused by low genetic diversity and slow regeneration. **Originality**: This study addresses a gap in existing research by synthesizing the current status and proposing a comprehensive conservation framework for *D. celebica*, a species at risk of extinction.

KEYWORDS: *Diospyros*; endemic; Macassar ebony; vulnerable.

1. Introduction

The Diospyros genus contains valuable wood species that are vital to ecosystems across tropical regions. Besides timber, these species provide important economic resources, such as non-timber forest products, and have high horticultural value (Darmawan et al., 2021). Diospyros, part of the Ebenaceae family, is an ecologically and economically significant group of flowering plants that includes numerous ebony and persimmon species. The genus comprises over 500 species worldwide. In Africa, African ebony is intensively used in food, medicine, lumber, construction, and cultural practices. Wood from black or striped wood is used to make a wide variety of items, including walking sticks, pool cues, door handles, tool handles, and more (Yves et al., 2024).

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Sulawesi ebony, also called Macassar ebony (*Diospyros celebica* Bakh.), is a type of ebony native to Indonesia's island of Sulawesi. This species has been classified as Vulnerable in the IUCN Red List category (WCMC, 1998). *Diospyros celebica* Bakh., a member of the family Ebenaceae, represents one of Indonesia's most economically and ecologically significant endemic tree species. Native to Sulawesi, this species has garnered international attention for its high-quality ebonywood and its role as an essential component of Indonesia's traditional medicine system. Conserving Diospyros in botanical gardens is essential given its ecological and economic significance, as it supports detailed studies of its biology and the development of sustainable applications (Abywijaya et al., 2024). Sulawesi, Indonesia, hosts approximately 5,000 flowering plant species, of which 15% are endemic. The endemic ebony (*Diospyros celebica* Bakh.) is well-known locally as ebony. This species yields luxury, high-value wood and was declared the mascot of Central Sulawesi Province in Decree No. 660/78/1995, issued on February 27, 1995. While the genus ebony includes 90-100 tree species, only a select few produce patio wood. This type of ebony wood is considered luxurious due to its stunning pattern and substantial strength, making it highly sought after. *Diospyros celebica* Bakh has a lengthy growth period, often lasting hundreds or even thousands of years. This species is an evergreen broad-leaved tree that can reach heights of up to 40 meters and a trunk diameter of up to 1 meter (Chen et al., 2018).

This type yields luxurious wood, characterized by a shiny black core with black-brown stripes. Currently, remaining ebony stands face threats from human activities such as illegal logging and land conversion for plantations. Conversely, the demand for ebony seeds in both in-situ and ex-situ conservation is significant, and therefore, information on their potential and natural range is essential required. Ebony wood has been a highly valued trade item since the Dutch colonial era. Therefore, this species of wood presents enormous opportunities for market demand. Japan, Korea, and Taiwan were export destinations for ebony from 1969 to 1984. Since colonial times, ebony wood has been known as Macassar ebony, striped ebony, and coromandel, and it is traded to European and Asian countries. Ebony's decorative appeal is highly valued due to its heavy, strong, and durable nature, earning it the classification of ornamental wood. It is used in furniture, sculptures, carvings, fans, decorative veneers, musical instruments, and souvenirs (Allo, 2020; Rukmi et al., 2023). Sustainable forest management for ebony involves adhering to the principle of no over-logging. The six ebony species designated as Luxury Wood Class I each have unique attractions, especially in terms of price. (Prasetyo et al., 2022). The distribution and potential of ebony in Sulawesi are currently not well mapped, considering the rampant illegal logging activities and land conversion for settlements that have an impact on the condition of natural stands in Sulawesi's natural forests. Declines in the quantity and quality of trees, including ebony, as key components in natural forests, can influence the structure of forest vegetation, forming resilient stands that reflect the dynamics of natural regeneration (Fatlan et al., 2021). Ebony has been widely used to make carvings, inlays, furniture, and musical instruments. It is estimated that the number of mature trees has decreased, and most of their habitat has been converted to other plantation types (Aldiansyah & Risna, 2023).

Diospyros celebica is a high-value wood that is widely used for furniture and crafts and is also used locally as a traditional antidiabetic remedy; Conservation combines in situ protection, ex situ collection and community participation, but the species is vulnerable to overexploitation and habitat loss. Despite *Diospyros celebica* having significant economic and ecological value as a Sulawesi-endemic species, a crucial research gap remains due to inadequate mapping of its spatial distribution and natural stock, caused by widespread habitat loss and insufficient documentation of illegal logging. Moreover, there is an urgent need to shift from descriptive reviews to critical analyses that incorporate advanced ecological concepts, such as ecosystem resilience and very low natural regeneration rates (only 1% at the pole level), to develop more strategic conservation approaches. Additional gaps include limited knowledge of genetic diversity and the effects of inbreeding depression on long-term population viability, as well as the need for innovative mass propagation techniques and multi-method forensic tools—like combining wood anatomy, isotopes, and

spectroscopy—to enhance ecosystem restoration efforts and law enforcement in its natural habitat. The basis of this research, as derived from the literature, is expected to provide clear direction for future conservation investigations and strategies. Its success will depend on coordinated efforts that integrate scientific research, conservation action, and community engagement to ensure that *D. celebica* continues to contribute to ecosystem health and benefits to humans.

2. Methods

A systematic review of academic literature was performed to assess the current status and use of *D. celebica* plants in Indonesia. The review followed Meta-Analysis guidelines, covering identification, screening, feasibility, and inclusion of relevant studies (Vu-Ngoc et al., 2018). The search focused on research articles from the last 10 years (2015 to 2025) related to *D. celebica*, Literature older than 10 years consisted of legislation and taxonomy. The literature review was conducted using Publish or Perish software on the Google Scholar and Scopus databases in October 2025. These two databases were chosen because they include a wide range of local, regional, and international journals from various fields, including natural, social, and interdisciplinary sciences, which aid the search keywords. The keywords *Diospyros celebica* were used in this study, which consisted of "*Diospyros celebica*" OR "botany *Diospyros celebica*" OR "phytochemical *Diospyros celebica*" AND "conservation of *Diospyros celebica*". There are no restrictions set on the year, language, or country of publication. Based on the query, generate 98 articles in Google Scholar and 52 in Scopus for a total of 150 articles. The analysis was conducted without a time limit to assess the extent of discussion of *Diospyros celebica* in two databases: Google Scholar and Scopus (Fig. 1).

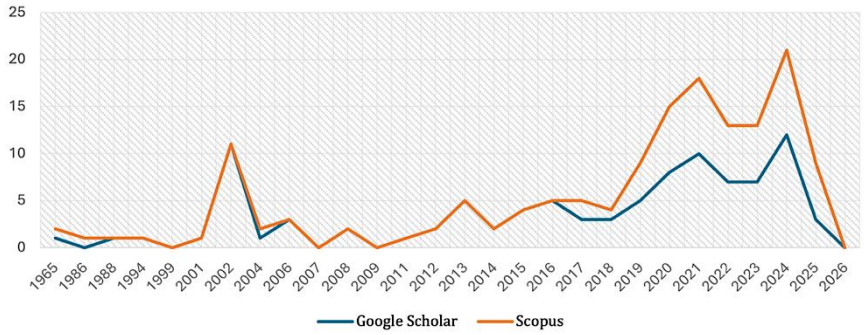


Fig 1. Total number of publications related to the keyword *Diospyros celebica* in the Google Scholar and Scopus databases

This literature study systematically seeks research that reports on the botany, ecology, traditional use, and conservation/preservation of *D. celebica* biodiversity, especially in Indonesia. Articles from Google Scholar and Scopus are filtered by reading titles and abstracts, and those reporting on their ecological, botanical, phytochemical, and conservation conditions are retained. Some data from Google Scholar and Scopus is imported into Mendeley's reference management software, and then duplicate entries are removed by comparing the search results from both databases.

After reading the article titles, 75 articles were excluded from a total of 150, leaving 75 for further analysis. After reading the abstracts of the remaining articles, we expect 19 articles; then 56 remain. The remaining articles (n = 56) were selected to read the full text in detail and, after sifting, to narrow it to n = 53, as 3 articles were included. The remaining 53 articles were declared eligible and therefore included in the analysis because they explicitly discussed their ecological, ethnobotanical, phytochemical, and conservation conditions. The filtering process for this article is shown in the PRISMA diagram in Fig. 2.

The 81 papers were excluded for the following reasons: they were not about ebony wood, did not discuss botanical descriptions or utilization, or analyzed contexts other than

conservation or conditions related to *Diospyros celebica*. Unpublished technical reports commissioned by government or Non-Governmental Agencies are also suspected to have originated from this study due to the lack of a comprehensive national database that would enable a systematic search for them. Although these observations are incomplete, they provide indicative explanations of the ecological conditions, traditional uses, pharmacological properties, phytochemical composition, and conservation of *Diospyros celebica* in Indonesia.

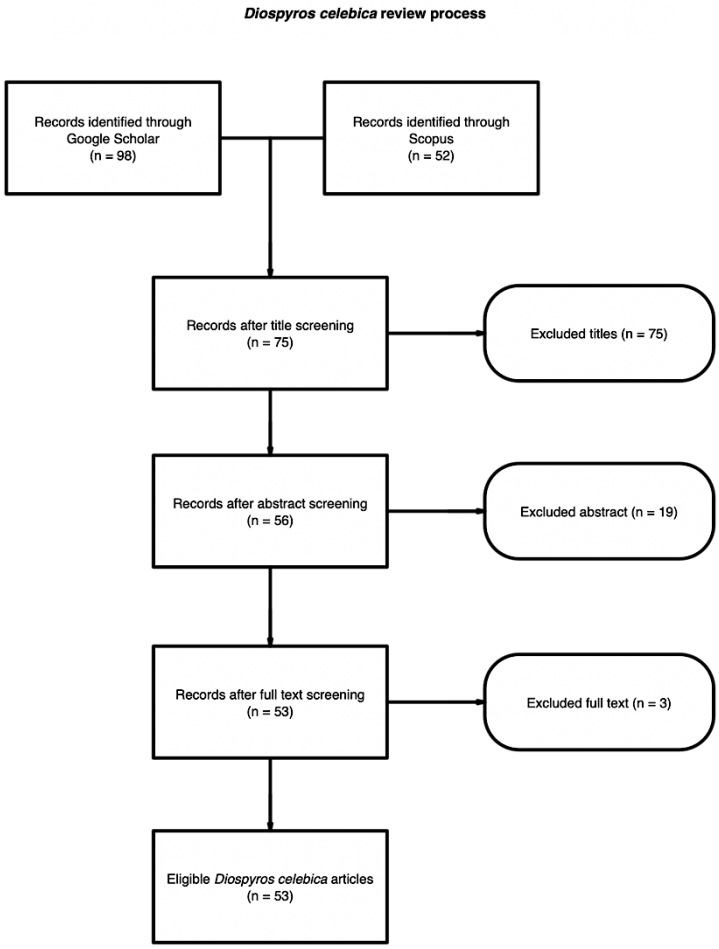


Fig 2. A PRISMA diagram workflow showing a scope review

The article selection process was conducted by considering the discussion aspects and the depth of the material in each article that supports the description of *D. celebica*. As shown in Fig. 2, the selection process occurred in three stages. The first stage involved sorting titles relevant to the discussion aspects of *D. celebica*. The second stage entailed reading the abstracts in full to assess their suitability as sources. The final stage was reading the entire articles to gain a more comprehensive understanding of various aspects of *D. celebica.* A total of 53 articles were obtained through the selection process, followed by data extraction, including descriptive information such as author and year. A thematic analysis was then conducted by grouping the research findings based on specific themes or topics relevant to the research questions. Furthermore, patterns were identified to highlight similarities, differences, contradictions, or interdisciplinary research gaps. The findings from the synthesis were then described in narrative form, as well as in figures and tables, and the limitations of this study were also identified.

An analysis of 53 available studies on the genus Diospyros reveals a wide range of research, with most focusing on the endemic species *Diospyros celebica* Bakh. Here is a

systematic table that highlights the methodology and research gaps identified from the titles and bibliographic sources (Table 1).

Table 1. List of articles synthesized from sorting results using the PRISMA diagram

No.	Author & Year	Title	Research Methods	Research/Contribution Gap
1	Abywijaya et al. (2024)	Phenotypic and Estimated Genetic Variability in Endemic *D. celebica* and *D. blancoi*	Analysis of phenotypic variability and estimation of genetic parameters.	Lack of genetic comparisons between endemic species and widely distributed species in ex-situ environments.
2	Aldiansyah & Risna (2023)	Assessing potential habitat suitability of vulnerable endemic species	Habitat suitability modeling (MaxEnt/GIS).	The need for critical habitat mapping for endangered endemic species in Sulawesi.
3	Apriandini et al. (2024)	Isolation and Characterization of Flavonol glycoside as Antioxidant and Antidiabetic	Isolation of compounds (ethanol extraction) and in vitro bioactivity assays.	Specific exploration of flavonol glycosides as antidiabetic agents of ebony leaves.
4	Asdar (2019)	Influence of Site on Streak Patterns and Physical Properties	Testing of the physical properties of wood based on the location of the grow.	The influence of microenvironmental factors on the formation of streak patterns in ebony wood.
5	Asdar et al. (2016)	Chemical Properties of *D. celebica* in Different Streaks Pattern and Radial Direction	Chemical analysis of wood (extractive, holocellulose, lignin) radially.	The relationship between the chemical composition of wood and the aesthetic pattern of wood lines is of high economic value.
6	Asdar et al. (2015)	Distribution, Potency And Quality ebony in Sulawesi	Field surveys and potential uptake mapping.	Data on the inventory of the distribution and potential quality of wood in Sulawesi's native habitat.
7	Boritnaban et al. (2022)	Metabolite Profiling of ebony Leaves and Wood Extracts Using LC-MS/MS	Metabolite profiling based on Liquid Chromatography-Tandem Mass Spectrometry.	Comprehensive identification of secondary metabolites in unmapped parts of wood and leaves.
8	Chen et al. (2018)	Molecules and functions of rosewood: *Diospyros celebica*	Systematic literature review.	Synthesis of data on the constituent molecules and biological functions of rosewood (ebony).
9	Chen et al. (2024)	Ethnomedicinal, Phytochemical, and Pharmacological Properties of *D. mollis*	An ethnomedic and phytochemical review.	Documentation of the pharmacological potential of *underutilized* D. mollis species.
10	Duncan et al. (2020)	Optimization of in vitro sterilization on ebony using shoot explants	Laboratory experimentation (tissue culture/sterilization).	High contamination constraints on the propagation of ebony in vitro.

11	Damanik & Amru (2022)	Carbon stocks Potential and economic value Valuation	Biomass estimation and carbon economic valuation.	There is a lack of studies on ebony's role in mitigating climate change through carbon stocks.
12	Darmawan et al. (2021)	Selected Properties of Macassar ebony from Plantation	Testing the mechanical and physical properties of plantation wood.	Comparison of the quality of ebony wood from natural forest vs plantation forests.
13	Fatlan et al. (2021)	Tree species diversity on ebony habitat with different degradation levels	Vegetation analysis and diversity index.	The impact of forest degradation on community structures in ebony habitats.
14	Handayani et al. (2020)	Antimicrobial activity of biosynthesized silver nanoparticles	Biosynthesis of silver nanoparticles (AgNPs) using plant extracts.	The use of waste or ebony parts for green nanotechnology applications (green synthesis).
15	Hanifah et al. (2025)	Natural Durability of Inner and Outer ebony Wood against Termites	Natural durability test against dry wood termites.	Variation in resistance between inner and outer sapwood to pests.
16	Hidayatullah et al. (2023)	Climate variables effect on ebony leaf morphology	Morphometric analysis and climate correlation.	Response of ebony leaf morphological plasticity to changes in regional climate variables.
17	Huseynov et al. (2025)	Bioregional, Bioecological, and Potential Medicinal Significance of Sharon	An ecophysiological and bioregional review.	Biological adaptation and medical significance of the *genus Diospyros* globally.
18	Ihwan et al. (2023)	Activity Of ebony Leaf Extract Against Diabetic Wounds	In vivo assay in aloxan-induced white rats.	The potential of ebony leaf extract in accelerating the healing of diabetic wounds.
19	Karlinasari et al. (2020)	Determination of Extractive Content of ebony by Near-Infrared Spectroscopy	NIR spectroscopy and chemometrics.	Development of a non-destructive method for the detection of wood extractive content.
20	Khan et al. (2020)	Morphological, microscopic, and physicochemical studies of *D. montana*	Microscopy and physicochemical studies.	Characterization of anatomical and microscopic details of *D. montana species*.
21	Allo (2020)	EBONY (*Diospyros celebica* Bakh) CONSERVATION	A review of conservation strategies.	The challenge of ebony conservation amid overexploitation and habitat degradation.
22	Lamanda et al. (2025)	Potential of rhizosphere bacteria producing IAA and gibberellic	Isolation of rhizosphere bacteria and hormone production test (IAA/GA).	Exploration of soil microbes that support the growth of ebony seedlings in Maros.
23	Larekeng et al. (2024)	Physiological Activity and	Biofertilizer experiments.	Optimization of ebony seed growth through a

		Growth Analysis of ebony Seedlings		combination of biological fertilizers.
24	Larekeng et al. (2016)	Polymorphism of SSR Regions in Sulawesi ebony	Simple Sequence Repeat (SSR) molecular marker analysis.	Evaluation of genetic polymorphisms in ebony populations in experimental forests.
25	Guli et al. (2024)	Antibacterial effectiveness of *D. celebica* against S. aureus	Antibacterial disc diffusion/microdilution test.	Effectiveness of leaf extracts against human pathogens (S. aureus and S. typhi).
26	Majiidu et al. (2024)	Microsatellite Identification Based on Genome Assembly	Bioinformatics analysis and genome assembly.	Development of genome-based microsatellite markings for ebony population studies.
27	Mukrimin et al. (2021)	Fungal diversity inhabiting tissues of ebony in urban forest	Identification of endophytic fungi (culture and molecular).	An inventory of the diversity of fungi associated with the ebony network in urban forests.
28	Ariani et al. (2025)	Antimicrobial Potential of Gold Nanoparticles using Seed Extract	Biosynthesis of gold nanoparticles (AuNPs).	The use of ebony seed extract as a reducing agent in the synthesis of gold nanoparticles.
29	Nugrahani et al. (2020)	Antibacterial activity of ebony wood powder fraction	Fractionation and antibacterial tests against E. coli.	Identify the specific fraction of ebony wood powder that has the strongest antibacterial activity.
30	Paembonan et al. (2021)	Dynamics of physiological properties based on crown and altitude	Measurement of physiological parameters (photosynthesis/chlorophyll).	ebony physiological response to the position of the crown and the height of the growing place.
31	Prasetyo et al. (2022)	Current Distribution of *Diospyros* spp. with Its Climatic Information	Global biodiversity data analysis (GBIF/Web-based).	Mapping the global distribution of the genus *Diospyros* is associated with macroclimate variables.
32	Ancient & Sembiring (2022)	Isolation and Identification of Phenolic Compounds from Leaves	Isolate phenolic compounds.	Characterization of specific phenolic compounds contained in ebony leaves.
33	Djamil et al. (2024)	Flavonoid Compound as An Antidiabetic Candidate	Isolation and identification of flavonoids.	Determination of specific flavonoid compounds as candidates for antidiabetic phytopharmaceuticals.
34	Ramadhan et al. (2023)	Phytochemical analysis and antioxidant activities of 3 species	Alpha-glucosidase inhibition and antioxidant activity test.	Comparison of biological activity between three species *of Diospyros* from East Kalimantan.
35	Rauf et al. (2024)	Anticancer therapeutic potential of genus *Diospyros*	Comprehensive review (Review).	The therapeutic potential of Diospyros-derived compounds in the treatment of cancer.

36	Rauf et al. (2017)	*Diospyros*, an under-utilized, multi-purpose plant genus	Overview of plant utilization.	Lack of optimization of the utilization of *the Diospyros* genus as a multipurpose plant.
37	Restu et al. (2017)	High Outcrossing Rate And Pollen Dispersal Distance	Gene flow analysis (molecular marking).	A study of mating systems and pollen dispersion distances in Sulawesi's endemic species.
38	Rukmi et al. (2023)	Potential, Distribution Pattern and Autecology	Analysis of autechology and spatial patterns.	Specific ecological characteristics of seed stands in Central Sulawesi.
39	Saleha & Ngakan (2016)	Distribution and Population Structure of the Juvenile	Analysis of population structure (youth level).	The dynamics of natural regeneration of ebony under the shade of the mother tree.
40	Salindeho et al. (2023)	Understanding *D. rumphii* through Long-read sequences	Sequencing analysis (Oxford Nanopore Technologies).	The use of third-generation sequencing technology to understand the genomics *of D. rumphii*.
41	Sandratriniaina et al. (2021)	Comparative wood anatomy of 15 Malagasy *Diospyros* species	Comparative anatomy analysis of wood.	Identification of distinguishing anatomical features in 15 species *of Diospyros* from Madagascar.
42	Sasmita et al. (2019)	Antioxidant Potential Of Secondary Metabolites Of Bark	Ethyl acetate fractionation and antioxidant test.	Exploration of the antioxidant potential of secondary metabolites of ebony bark.
43	Siregar et al. (2022)	Wood core samples for multi-purpose analysis using pickering punch	Development of sampling tools/methods (Pickering punch).	Innovative efficient sampling of wood cores for multi-purpose analysis.
44	Suhartati & Alfaizin (2020)	ebony (*Diospyros celebica* Bakh.) cultivation: A short review	A review of cultivation techniques.	Summary of challenges and best practices in ebony cultivation.
45	Sulastri et al. (2025)	Review: antibacterial and antifungal compounds, microbiome	An overview of the interaction of the microbiome and pathogens.	Dynamics of interaction between antimicrobial compounds and microbial communities in the genus *Diospyros*.
46	Cape et al. (2024)	Optimization of sterilization ebony leaf explants	Experimental (in vitro culture).	The technique suppresses the oxidation of phenolic compounds during the initiation of leaf tissue culture.
47	Wanda and Oksari (2019)	Ex situ Conservation of *Diospyros* spp. in Bogor Botanic Gardens	Evaluation of botanical garden collections.	The status of ex situ conservation success of various *species of Diospyros* in Indonesia.
48	Wulandari et al. (2024a)	Morphological variation of	Analysis of the character of vegetative organs.	Morphological variation between species *of Diospyros* native to

		Diospyros spp. native to Sulawesi		Sulawesi based on physical characteristics.
49	Wulandari et al. (2024b)	Morphological Variation (Journal Article version)	Characterization of vegetative morphology.	Phenotypic character deepening for taxonomic differentiation.
50	Yusran et al. (2023)	Mycorrhizal status of *Diospyros celebica* Bakh.	Mycorrhizal colonization analysis (soil/root microscopy).	The role of mycorrhizal symbiosis in supporting the survival of endangered species.
51	Yves et al. (2024)	Knowledge, Local Uses, and Vulnerability of African ebony	Ethnobotanical surveys and vulnerability assessments.	Documentation of local knowledge and the level of susceptibility *of D. crassiflora* in Cameroon.
52	Zhang et al. (2025)	Impact of drying parameter on the collapse shrinkage	Experimental wood drying (drying kinetics).	Collapse shrinkage problems in Macassar ebony wood during the processing process.
53	Zuas et al. (2025)	Biosynthesis and Characterization of Silver Nanoparticles	Physicochemical characterization of nanoparticles.	Catalytic and antimicrobial activity of ebony seed extract-mediated nanoparticles.

3. Results and Discussion

3.1 Botanical description

Diospyros generally exhibit a tree- or shrub-like form and do not engage in grazing (species that do not graze). They lack terminal shoots, which are sometimes interchangeable and may feature transparent or hollow glandular spots. These plants produce dioecious or polygamous flowers. Flowers are typically axillary, rarely solitary, and tend to wilt soon after opening; stamens are four or more, often paired, forming two circles that can be arranged as sepals, petals, leaves, branches, stipules, or radially. The ovaries are usually rudimentary, solitary, and have stigmas that often possess a two-slit opening. Petals generally have three to five (sometimes seven), occasionally truncated lobes. The berries are fleshy, somewhat rough, and usually have stiff, enlarged petals. The seed count ranges from one to ten or more (Wanda & Oksari, 2019).

In Sulawesi Island's natural forests, Diospyros trees can grow up to 40 meters tall, with a net trunk height ranging from 10 to 21 meters and diameters reaching 100 cm. Large specimens may also have branches extending as high as 3 meters. At the end of the fruiting season, saplings become plentiful if conditions align with the rainy season. These natural saplings typically survive through the seedling stage, but may fail to do so if competition for space and light is intense. The regeneration rate for ebony species is quite low, with approximately 1 wild sapling per hectare, representing about 1%. In deforested areas, wild ebony saplings often appear unhealthy but tend to fare better than those in undisturbed natural forests (Suhartati & Alfaizin, 2020). The morphological similarities of *Diospyros* spp. Include the shape of the tree, the pyramid-shaped crown, and the development of monopodial central trunks. The stem is cylindrical, and the stem fibers are smooth. The branching pattern of *Diospyros* spp. is continuous, with horizontal branch growth. The leaves of *Diospyros* spp. are simple, with an alternating arrangement of leaves and semi-terete petioles located at the edges of the leaves. The leaves are symmetrical and have pointed leaf tips. The leaves of Diospyros spp. are typically greenish-yellow, featuring penninervis leaf veins. The venation pattern is pinnate, with areolar venation showing both single and double veins, and an ascending lateral venation pattern with anastomosis near the leaf edge. Additionally, the leaves display small glandular dots on their surfaces, a characteristic feature (Wulandari et al., 2024). *Diospyros celebica* has a distinctive shape and

description that distinguish it from the genus *Diospyros* in general; this is also evident in its elliptical, linear leaves measuring 12–35 cm × 2.5–7 cm (Fig. 3) (Abywijaya et al., 2024).

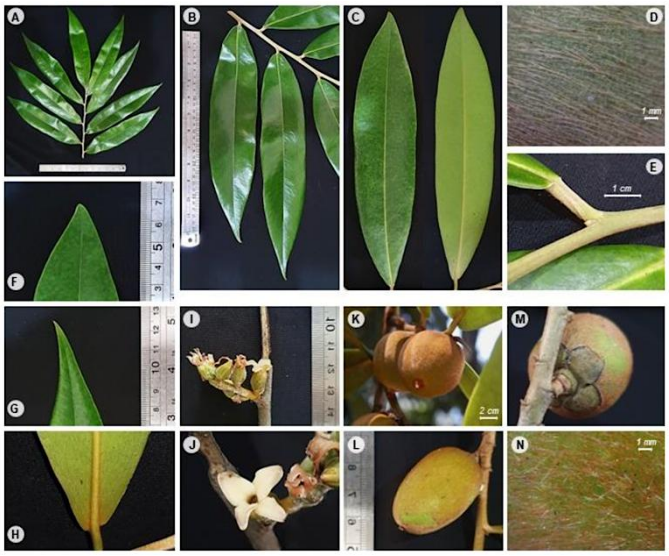
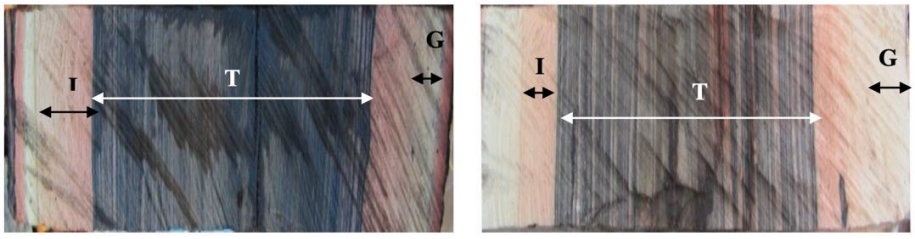


Fig. 3. Distinct morphological features of *Diospyros celebica* include: lanceolate leaves (A, B) with dark green upper surfaces (C-left) and yellowish-green undersides (C-right); the underside of the leaves is densely hairy with a silvery-brown hue (D); petioles are about one centimeter long (I); leaf apices are either acute (F) or acuminate (G), with cuneate bases (H); flowers are nearly one centimeter in size, featuring a creamy-colored corolla (I, H); and fruits are rounded (K) or ovoid (L, M), covered with dense to moderate brown hairs (K, L, M, N)
(Abywijaya et al., 2024)

The physiological characteristics of ebony (*Diospyros celebica* Bakh.) leaves, including stomatal number, size, index, and chlorophyll content, vary with crown position and elevation. Higher elevations are associated with a greater number of stomata, whereas stomatal size and stomatal index decrease with increasing height (Stuart et al., 2021). Ebony exporters in South Sulawesi and Central Sulawesi have specific standards for stroke patterns. Highest quality is characterized by thin, parallel black veins spaced almost equally. Lower-quality items feature broader, irregular strokes with varying thicknesses and inconsistent spacing. In the ebony industry, different types of macis rods (BM*, Batang Macis*) are recognized, including ebony with thin, uniform, parallel black streaks, and cobwebs (SL, Sarang Laba-laba), which display spaced, irregular strokes (Fig. 4) (Asdar, 2019). *D. celebica* wood has a distinctive look, characterized by reddish-brown, gray, or greenish-brown striped patterns, especially visible on porches (Karlinasari et al., 2020). Macassar ebony is an endemic tree species on Sulawesi that features striking black and brown streaks. This species needs specific environmental conditions to grow well, including appropriate altitude, light levels, and humidity (Stuart et al., 2021).



A B

Specification: G (Sapwood), I (medium), T (Core wood)

Fig. 4. Description of the types of strokes in *D. celebica*: A. *Batang Macis*, B. *Sarang Laba-laba*
(Asdar, 2019)

Ebony can thrive in shallow, rocky soils, as well as in conditions with moderate to high levels of organic matter. Ebony can thrive in climates with 1500 mm/year of rainfall, such as CD climates, and in various soil types like calcareous, sandy, loam, and rocky soils at an altitude of 400 meters above sea level (Aldiansyah & Risna, 2023). This species exhibits slow growth, which increases its vulnerability to extinction. Additionally, ebony seeds are recalcitrant, meaning they cannot be stored for long periods. Factors influencing seed germination include seed ripeness, size, and weight seeds. Macassar ebony wood has a density of 843.3 kg m-3, an anisotropy coefficient of 1.44 (good stability), an elasticity modulus of 10317.5 MPa, and a fracture modulus of 98.0 MPa. Macassar ebony wood is classified as very durable (class I) due to its resistance to termites and weathering fungi. The toxic compounds identified through gas chromatography-mass spectrometry (GCMS) and nuclear magnetic resonance (NMR) include dimethylnaphtol, dimethylnaphtol trimethylsilane, and gallic acid trimethylsilane (Darmawan et al., 2021).

To promote faster growth, Biofertilizer is applied to support SP2 ebony seed coating treatment, which includes a 45% Penicillium microbial solution and seed coating. This ensures optimal results across various growth and physiological parameters of ebony seeds. Treatment with seed immersion in microbes will enable the production of a higher percentage of seedlings across all variables (Larekeng et al., 2024). One example of utilization in other types of ebony is in Maleali ebony, which exhibits tree-level importance at 72.43%, stake-level at 45.63%, and seedling-level at 24.23%. The second pole level has a species importance value of 35.68% (Rukmi et al., 2023). Macassar ebony lacks a distinct growth cycle and can potentially produce more than one cycle per year. It is also classified as resistant to termite attacks. Resistance to rot may vary with radial position, or the distance from the pith to the bark, where the wood is used (Fig. 5) (Darmawan et al., 2021).

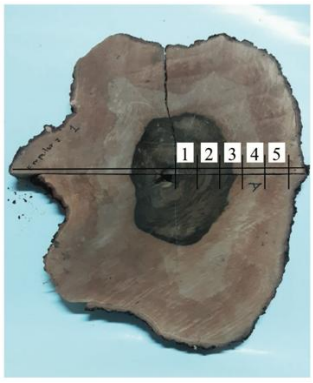


Fig. 5. A cross-section of the Macassar ebony wood sample disc illustrating radial increase numbers: 1 and 2 for core wood, 3 for the transition zone, and 4 and 5 for sapwood (Darmawan et al., 2021)

3.2 Description of its ecology and distribution

The natural habitat of Macassar ebony (*Diospyros celebica*) spans Gowa, Maros, Pangkep, Barru, Sidenreng Rappang, Luwu, East Luwu (South Sulawesi Province), Mamuju (West Sulawesi Province), Donggala, Parigi Moutong, Poso, and Morowali (Central Sulawesi Province). The highest stand stock, approximately 95.05 m^3 per hectare, was recorded in Cenrana, Maros. Most of the remaining ebony habitats are located within protected areas. Wood quality classes A and B are present in Sausu and Poso, whereas other regions are classified as class C (Fig. 6) (Asdar et al., 2015).

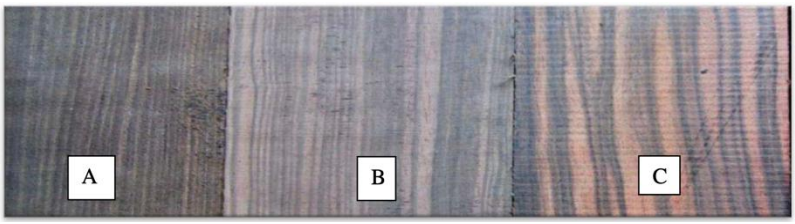


Fig. 6. The classification standard is three classes of quality ebony wood (class A, B, and C) (Asdar et al., 2015)

The pattern of distribution of Sulawesi ebony pollen occurs through cross-pollination between donor trees. Based on heredity analysis, the ebony female elder is the dominant cross-pollination species among elders from *D. celebica*. On the island of Sulawesi, the range of pollen dispersal is 0 – 166 m (Restu et al., 2017; Fatlan et al., 2021). Ebony is classified into three species within the world's tropical regions, with three dominant species—*D. celebica* Bakh*, D. lolin* Bakh*,* and *D. rumphii* Bakh—found in Indonesia. In Indonesia, ebony species experience annual rainfall between 1,722 and 4,013 mm and temperatures ranging from 23.4 to 27.2°C. This information on distribution and climate conditions provides a foundation for further research, such as land-suitability studies using species distribution models (Prasetyo et al., 2022).

Ecologically, *D. celebica* is classified as a vulnerable and endangered endemic species. Biodiversity loss in ebony habitat extends beyond a decline in parent tree populations to include changes in the structure of surrounding vegetation communities caused by varying levels of forest degradation (Aldiansyah & Risna, 2023; Abywijaya et al., 2024). Genetic gaps result from habitat fragmentation, yet studies indicate that this species maintains a high outcrossing rate and significant pollen dispersal distances, which could theoretically support gene flow. Nonetheless, low phenotypic and genetic variability in some populations, both in natural habitats and ex situ collections, signal a risk of inbreeding depression that might diminish adaptability to climate change (Ramadhan et al., 2023; Abywijaya et al., 2024; Huseynov et al., 2025).

Macassar ebony offers a diverse range of ecosystem services, including climate regulation and pharmacological potential. Notably, it contributes to carbon sequestration, as ebony stands possess significant carbon stock potential. When managed sustainably, these stands provide economic value through carbon valuation schemes, contributing to global efforts in climate change mitigation (Dalauleng et al., 2020; Damanik & Amru, 2022). Moreover, the survival of the ebony forest ecosystem depends significantly on rhizome interactions. Mycorrhizae and rhizosphere bacteria that produce growth hormones such as IAA and gibberellins are essential for nutrient cycling and for maintaining soil health in its natural habitat (Allo, 2020; Yusran et al., 2023; Yves et al., 2024). Conversely, ensuring the long-term sustainability of *D. celebica* necessitates an upstream-downstream approach that integrates conventional methods with biotechnology, including in situ and ex situ strategies. Conservation efforts within native habitats should be complemented by strengthening collections in botanical gardens that serve as genetic reserves. Monitoring juvenile populations under the shade of parent trees is a vital indicator of healthy natural regeneration (Saleha & Ngakan, 2016; Restu & Larekeng, 2017; Aldiansyah & Risna, 2023).

D. celebica was recorded in 26 presence data in 3 countries. Especially in Indonesia, this species is recorded in Sulawesi and Papua. *D. celebica* has been identified to have a variety of extractive substances at its growth sites in West Sulawesi, Central Sulawesi, and South Sulawesi Province. Three species of ebony are distributed in the tropics, and the other three species (*D. celebica* Bakh, *D. rumphii* Bakh, and *D. lolin* Bakh) are mostly found in Indonesia (Prasetyo et al., 2022). Distribution of *Diospyros celebica* in Indonesia and Malaysia (Fig. 7).

Fig. 7. Distribution of *Diospyros celebica* Bakh. in Indonesia and Malaysia. (GBIF, 2023)

In addition, this distribution is reinforced by another record from Aldiansyah & Risna (2023). There were 47 cases of *D. celebica* Bakh and 1,557 cases of *R. cassidix*. These incidents were reported across nearly all regions of Sulawesi, with higher concentrations in North Sulawesi, Central Sulawesi, and South Sulawesi. *D. celebica* Bakh species have a concentrated distribution in Central Sulawesi (North Morowali, and the south coast of Banggai) and South Sulawesi (East Luwu, North Luwu, North Toraja, Barru, Pangkep, Maros, Sidrap, Wajo, Sidenreng Rappang, and Gowa) (Fig. 8). *D. celebica*, endemic to Sulawesi, and the widespread *D. blancoi* are two important species of Diospyros (persimmon and ebony genus) preserved in Indonesian botanical gardens. *D. celebica* populations are distributed across different areas in Sulawesi, giving rise to various ecological varieties or origins (Abywijaya et al., 2024).

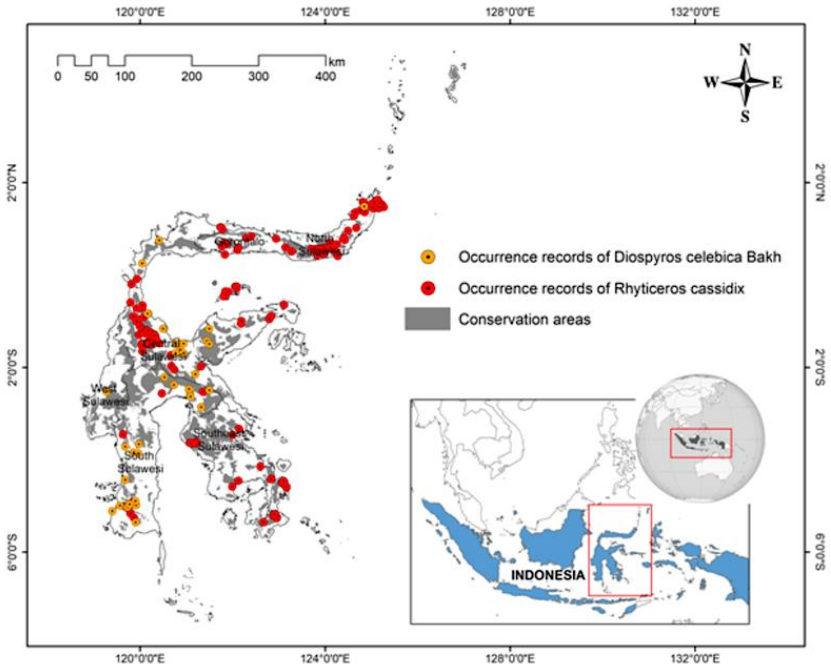


Fig. 8. The occurrence records of *D. celebica* Bakh and *R. cassidix* in Sulawesi (Aldiansyah & Risna, 2023)

Conservation and restoration efforts for vulnerable Macassar ebony populations can leverage understanding of their genetic makeup. Among the findings, 14 contigs feature a dinucleotide motif, 12,090 contigs have a trinucleotide motif, 780 contigs display a tetranucleotide motif, and 6 contigs include a pentanucleotide motif. These results provide essential information for further exploring the genetic diversity and structure of Macassar ebony, informing future conservation and cultivation strategies (Majiidu et al., 2024).

Ebony is classified as vulnerable because its population is decreasing, mainly due to timber demand that isn't balanced by successful cultivation. In natural ecosystems, its

growth is affected by climate conditions and soil characteristics, which influence stand productivity and resilience, including morphological features responses. Climate variables such as temperature, rainfall, and the length of sunlight exposure are significantly related to the morphology of ebony leaves. In addition, the classification results used a support vector machine to identify the morphology of ebony leaves, and the region obtained an average accuracy rate of 86.89%. In addition, other external factors such as insect pests attack leaves in the field, including leaf-cutter bees (*Megachile* sp.) and caterpillars of the Lepidoptera order, such as *Pycnonotus aurigaster, Centropus bengalensis, Phaenicophaeus calyorhynchus, Hypothymis azurea*, and *Oecophylla smaragdina* (Hidayatullah et al., 2023; Sulastri et al., 2025).

Therefore, integrating biotechnology for in vitro mass propagation poses significant challenges due to high rates of contamination and phenolic compound oxidation in explants. Optimizing sterilization methods and using biofertilizers are essential to accelerating population recovery on degraded land. Another potential solution is to improve management based on genomic data. Utilizing the latest sequencing technology (long-read sequencing) and developing genome-based microsatellite markers are crucial for mapping suitable conservation management units to prevent further genetic erosion (Allo, 2020; Dalauleng et al., 2020; Larekeng et al., 2024; Majiidu et al., 2024; Tanjung et al., 2024; Lamanda et al., 2025; Sulastri et al., 2025). The ecological consequences of the decline in Diospyros populations extend beyond local effects, such as the loss of a valuable timber species, and are systemic, affecting the functions of tropical forest ecosystems and their underexplored biochemical potential. Sustainable conservation efforts require integrating habitat protection policies, genomic technology, and local wisdom to manage species vulnerability.

3.3 Commercial timber utilization

The treatment of ebony considers the color and pattern of the core wood strokes. Raw materials for furniture, such as butsudan, favor darker patio wood with smooth, dense black strokes and thin brown strokes like *Batang Macis*. In contrast, ebony with black strokes and brighter, wider brown strokes like *Saring Laba-laba* is ideal for crafts and carvings. Consumers in Japan and China prefer ebony with regular, smooth black streaks, while Europeans favor ebony with thicker, more sparse black streaks or broader brown streaks. (Asdar, 2019). Ebony remains a highly valuable material, attracting widespread interest. It is commonly used in luxury furniture, sculptures, carvings, fans, lathes, decorative tools, brush handles, premium veneers, and inflatable musical instruments (Boritnaban et al., 2022).

The economic value of the potential carbon reserves in the ebony stand examined here is projected to grow as the World Bank Group anticipates the carbon selling price rising to USD 50–100 per ton by 2030. The stand with the highest carbon stock potential is *Diospyros rumphii*, at 74.25 tons per hectare, followed by *Diospyros celebica* at 67.77 tons per hectare, and *Diospyros ebenum* at 64.98 tons per hectare tons/ha. The highest economic valuation of carbon stock potential is in the *Diospyros rumphii* stand, valued at USD 148.49, or approximately IDR 2,132,048. This is followed by *Diospyros celebica*, valued at USD 135.54, or about IDR 1,946,025. Lastly, the potential carbon stock valuation for *Diospyros ebenum* is USD 129.95, or roughly IDR 1,865,879 (Damanik & Amru, 2022).

Macassar ebony can be dried effectively to preserve its quality and enhance its market value. A fungus mainly found on Diospyros plants can produce IAA, a hormone that may serve as a biological growth promoter. Consequently, the commercial potential of Diospyros should be weighed alongside sustainable cultivation practices (Zhang et al., 2025; Sulastri et al., 2025). Ebony wood over 60 years old has a high extractive content. Extractive substances have toxic properties so wood-destroying organisms do not like them. Ebony wood has been proven to have a higher durability grade than pine wood, especially on the inside of the wood it is very suitable for use in constructions that require high resistance to termite attacks (Hanifah et al., 2025). Additionally, in nanotechnology applications, the use

of ebony seed and leaf extracts in the biosynthesis of silver nanoparticles (AgNPs) and gold (AuNPs) demonstrates potential for supporting ecosystem services in eco-friendly green technology (Mukrimin et al., 2021; Ariani et al., 2025; Zhang et al., 2025; Zuas et al., 2025).

3.4 Phytochemistry and pharmacology

According to multiple studies, chemical analysis of Macassar ebony typically reveals high levels of bioactive compounds and hemicellulose. Ebony wood also contains higher amounts of cellulose, lignin, ethanol-toluene extractives, pH, and ash, distinguishing it significantly from sapwood and intermediate types (Asdar et al., 2016). Diospyros is among the few plant genera that serve multiple purposes, including food, medicine, and wood. Various species within this genus have yielded phytochemical compounds such as terpenoids, polyphenols, tannins, hydrocarbons, lipids, benzopiron, naphthokuinone, oleanane, and taraxerana. These plants exhibit a range of biological activities—such as antioxidant, anti-inflammatory, analgesic, antipyretic, antidiabetic, antibacterial, anthelmintic, antihypertensive, and cosmetic effects—that have been confirmed through in vitro, in vivo, and clinical studies (Rauf et al., 2017).

In addition to compounds, mushrooms can be extracted from ebony roots for their potential as antioxidants, anti-inflammatory agents, and pain relievers. Several fungal species have been identified from ebony roots, including seven genera: Aspergillus, Penicillium, Gliocladium, Trichoderma, Fusarium, Rhizopus, and Phytophthora. Among these, Aspergillus and Penicillium are the most common, found both within the tree tissues and in the soil beneath ebony stands (Mukrimin et al., 2021). Diospyros contain a variety of ingredients and bioactives traditionally used for medicinal purposes. These are employed to treat infections (such as antifungal, antibacterial, antiviral, and anthelmintic conditions), gastrointestinal issues (including nausea, flatulence, dysentery, and diarrhea), and oral health problems (such as healing oral sores, toothache, and maintaining oral hygiene). Additionally, it is used for urogenital conditions (including antihemorrhagic effects, dysmenorrhea, and infertility), skin diseases (such as dermatitis and new wounds), and other ailments like diabetes, internal wounds, antidotes, hemostatic drugs, and snakebites (Table 2).

Table 2. Descriptions of the compounds in *D. celebica* and their bioactive activities are summarized from various related research literature.

Compound Name	Description of uses	Literature sources
6a,12a-Dihydro-6H-(1,3) dioxone (5,6) ben zofuro (3,2-c) chrome-3-ol	Antiangiogenic activity	(Chen et al., 2018)
Benzene, 1,2,3-trimetoxy-5-(2-propenil)-	Antioxidant, anti-inflammatory, antithrombosis, and hypolipidemic	
3-O-Methyl-d-glucose	protects pancreatic B cells from allocant toxicity	
P-Cresol	Endothelial dysfunction in uremic patients, and can repair wounds and reduce endothelial progression cough and phlegm medicine, detoxification	
Coarse ethanol extract and ethyl acetate extract and ethanol residue	Antidiabetic action with α-glucosidase inhibiting activity	(Ramadhan et al., 2023)
Diomelquinone, O-Naphthoquinone, Celebaquinone,	Antifungal activity and toxic to fungi, such as Gallic, a fungal decay toxin	(Karlinasari et al., 2020) (Sulastri et al., 2025)

Isocelebaquinone, and DiosIndigo		
Ethanol leaf extract	Antioxidant activity of compound Fr.36-13a inhibitor αglucosidase	(Apriandini et al., 2024)
Fr.36-13a (Kaempferol3-O-β-glucoside)	Powerful antioxidant and antidiabetic activity by capturing DPPH radicals and inhibiting the enzyme α-glucosidase	
Silver nanoparticles (AgNP)	Antimicrobial properties against Escherichia coli and Staphylococcus aureus	(Handayani et al., 2020; Zuas et al., 2025)
Seed water extract in colloidal Au-NPs biosynthesis	Reduces trivalent Ag3+ to metallic gold Flavan-3-ol Galloylated Phenolic and Simple Phenolic Acids	(Ariani et al., 2025)
flavonoid 3,5-digalloyl-(-)-epiafzelechin	Antidiabetic drug candidates	(Djamil et al., 2024)
Secondary metabolites of the ebony bark ethyl acetate fraction	Antioxidant compound and classified as a strong antioxidant with an IC50 value of 75.47 µg/mL	(Sasmita et al., 2019)
flavonoids, terpenoids, amino aldehydes, alkaloids, quinones, phenolic acids, steroids, amino acids, fatty acids, and saccharides	antidiabetic, antibacterial, antifungal, and antiviral	(Boritnaban et al., 2022; Guli et al., 2024)
ebony leaf extract gel	Improved lesions in diabetic lesions of 10% concentration, with a healing percentage of 94.34% in white rats	(Ihwan et al., 2023)
Phenolic compounds of ebony leaves	Secondary metabolites	(Purba & Sembiring, 2022)
Steroids in the n-hexane and terpenoid fractions, phenolics, steroids in the ethyl acetate fraction	Fungicide *Phytophthora* and bactericidal bactericide *Staphylococcus aureus*	(Nugrahani et al., 2020)
saponins, fibers, and flavonoids in *Diospyros montana*	Antidiabetic, antibacterial	(Khan et al., 2020)
Caucasian persimmon gene (*D. lotus L.*),	Antidiabetic	(Huseynov et al., 2025)

The genus Diospyros is regarded as a promising source of potent anticancer compounds, containing a diverse range of phytochemicals with inherent therapeutic properties. Its anticancer effects include inhibiting cell proliferation, inducing apoptosis, and reducing angiogenesis, suggesting potential uses in cancer treatment ethnopharmacology. As modern research explores new approaches to combat diseases such as cancer, the genus *Diospyros* may emerge as a promising pathway for producing innovative and effective therapeutic agents (Rauf et al., 2024).

The genus *Diospyros* includes species worldwide, with more than 500 of them known for their significant health benefits. Among them, *Diospyros mollis* Griff. It has been used as a tonic and treatment for various indigestion-related diseases and intestinal parasites. *D. mollis* contains a wide range of chemical contents such as naphthalene and naphthokuinone derivatives, triterpenoids, alkaloids, sterols, glycosides, and fatty acid esters isolated from

the berries, roots, bark, and leaves of this species, with several pharmacological effects and other applications (Chen et al., 2024).

3.5 Conservation and challenges

3.5.1 Conservation status

Macassar ebony is a valuable luxury wood, recognized as the mascot of Central Sulawesi Province by the Governor's Decree No. 660/78/1995 on February 27 1995. According to Aldiansyah & Risna (2023), ebony has been widely used to make carvings, inlays, furniture, and musical instruments. The estimated number of mature trees has decreased, with much of their habitat converted to other plantation types. Among the 100 Diospyros species in Indonesia, only seven are officially recognized as ebony, including *Diospyros pilotanthera*, *Diospyros lolin*, *Diospyros macrophylla*, *Diospyros ebenum*, *Diospyros celebica*, *Diospyros ferea*, and *Diospyros rumphii*. The sought-after qualities of ebony wood in the international market have made it a highly valuable timber, leading to extensive exploitation. This overharvesting has caused a significant decline in ebony trees in their natural habitats, particularly in Sulawesi, as noted by Damanik & Amru (2022).

Ebony wood is utilized in construction, luxury furniture, carvings, decorative objects, and musical instruments. Its high demand and cost have driven increased logging in natural forests and an increase in illegal logging. The IUCN Red List classifies ebony as a vulnerable species (Fig. 9) (Karlinasari et al., 2020).

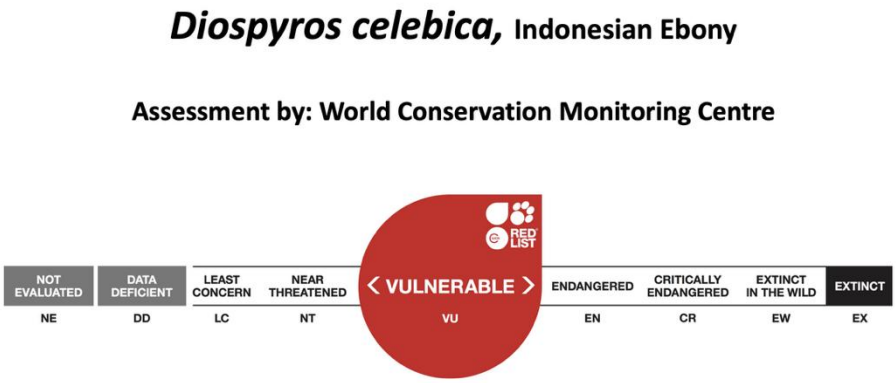


Fig. 9. The status of *Diospyros celebica* is categorized by the IUCN as a vulnerable species. (IUCN, 1998)

Sandratriniaina et al. (2021) note that many species, especially Diospyros, are overexploited in regions like Madagascar due to both local and international trade. Despite its importance for forensic identification, little is known about its wood anatomy. Wood anatomy is vital for promoting the sustainable and fair use of Diospyros species and aiding law enforcement efforts to combat illegal logging and protect endangered species. *Diospyros celebica*, a valuable species within the genus that includes persimmon and ebony, is preserved in Indonesian botanical gardens. Recognizing biological differences between endemic and widespread species is also crucial for plant conservation (Abywijaya et al., 2024).

Within a conservation framework, genetic variation is essential for a species' capacity to withstand environmental challenges and stress. Studies on *Diospyros celebica* (Macassar Eboni) show a gap between phenotypic variability and estimated genetic parameters. Although high outcrossing rates and relatively long pollen dispersal distances were observed in endemic populations in Sulawesi, these are natural mechanisms that sustain gene flow despite habitat fragmentation (Restu & Larekeng, 2017; Aldiansyah & Risna, 2023; Rukmi et al., 2023; Abywijaya et al., 2024). The vulnerability of endemic species like *D. celebica* is heavily affected by shrinking habitat suitability. Modeling potential habitats based on climate variables reveals that this species has specific tolerance limits for

microenvironmental factors. Climate variables not only affect spatial distribution but also drive morphological plasticity in vegetative organs such as leaves (Prasetyo et al., 2022; Purba & Sembiring, 2022; Hidayatullah et al., 2023; Huseynov et al., 2025).

3.5.2 Conservation challenges and strategies

The Diospyros genus is rich in secondary metabolites, including flavonol glycosides, flavonoids, and phenolics, which function as defense mechanisms against pathogens and herbivores. The extinction of these species results in the loss of a natural chemical reservoir that could serve as antioxidants, antidiabetics, and antimicrobial agents for human use (Chen et al., 2018; Karlinasari et al., 2020; Boritnaban et al., 2022; Apriandini et al., 2024; Tanjung et al., 2024; Sulastri et al., 2025). The functionality of ebony wood, including its aesthetic streak pattern and inherent durability, is greatly affected by site conditions and the ecological health of its stand. If these species become locally extinct, the loss of superior genotypes that can produce high-quality timber may occur, although this has not been fully documented scientifically (Asdar et al., 2016; Dalauleng et al., 2020; Damanik & Amru, 2022; Guli et al., 2024; Majiidu et al., 2024). The *D. celebica* provenance examined exhibited higher homozygosity, likely resulting from self-pollination or breeding among related plants, leading to a genetic diversity of just 95.4% relative to other species. Such a limited genetic base can often result in weak genetic stock due to inbreeding depression. To avoid the risk of Sulawesi ebony becoming endangered, implementing a conservation strategy is essential (Restu et al., 2017).

Conservation efforts for genetic resources, both in situ and ex situ, have been implemented in Sulawesi. Nonetheless, no additional initiatives have been made to manage ebony and its habitat. Policymakers must urgently improve conditions for growing and cultivating ebony before opportunities are lost. The development of ebony cultivation can be supported with comprehensive, current data on the distribution of remaining natural ebony forests, including stand characteristics and the potential for natural regeneration across different regions of Sulawesi. Potential seed stands must be identified and preserved to serve as seed sources for plantation programs. As Allo (2020) emphasizes, both central and local governments should implement strict regulations to safeguard natural ebony areas from encroachment. Since the management of ebony was broadened, various regulations have been introduced at the Ministry level, as shown in Table 3 (Allo, 2020).

Table 3. Regulations made by the Indonesian government to limit the exploitation of ebony

Regulation	Problem
Government Regulation Number 21 of 1970	Granting forest and forest management rights Proper harvesting
Ministry of Agriculture Title Number 54/Kpts/Um-2/1972	Felling of ebony trees above 60 centimeters
Decree of the Minister of Forestry Number 31/KPTS-IV/86	On the handling of ebony (including new logging ban)
Ministerial Decree No. 261/Kpts-V/1990	Protected tree species
Instruction of the Minister of Forestry Number 239/Minister of Finance-II/1996	Collection, Reduction and Sale of Used HPH Estates and former community logging in Central Sulawesi, that PT. INHUTANI II as the executor and ban on the export of ebony wood between islands in the form of logs
Governor's Decree. Central Sulawesi is not. 188.44/3932/Dinhut/1989	Determination of PangiBinanggan Nature Reserve in Central Sulawesi Province is a protected area ebony

(Allo, 2020)

In Indonesia, the Bogor Botanical Garden has gathered 32 Diospyros species, totaling 198 specimens. These species make up an ex situ conservation collection, primarily sourced

from Sulawesi. This plant collection is vital for research and has potential uses in building materials, handicrafts, household items, and more foodstuffs. The preservation of these plants is essential to ensure their availability and sustainable use (Wanda & Oksari, 2019). Ebony planting has occurred in various locations both within and outside the original site to ensure sustainability. The optimal time for planting ebony is at the start of the rainy season. Planting holes are prepared at least ten days prior, measuring 30 x 30 x 30 cm (Depth x Length x Width). Basic fertilizer application is tailored to the soil conditions. Infertile soils receive 20 grams of NPK (N (Nitrogen), P (Phosphate), and K (Potassium)) fertilizer per hole, while low-porosity soils are enriched with 3-4 kg of compost, charcoal, or plant powder (Suhartati & Alfaizin, 2020).

To ensure ebony's survival, high-quality seeds must be produced through tissue culture techniques. This method is used for clonal and mass propagation. The most effective sterilization of ebony shoot explants is achieved using bactericides and fungicides, which results in a contamination rate of 71%. Additionally, the lowest percentage of explants experiencing browning was 71% during sterilization. (Dalauleng et al., 2020). Furthermore, according to Larekeng et al. (2016), preventing ebony extinction requires conserving the species through breeding programs supported by genetically based molecular information. This molecular data will be invaluable for shortening and facilitating future ebony breeding efforts. Research by Saleha & Ngakan (2016) showed a relatively good growth rate of *D. celebica* seedlings. Most of the observed seedlings ranged from 11 cm to 20 cm in height. Saplings had diameters from 1.59 cm to 5.1 cm. For pole-stage seedlings, diameters typically ranged from 10.83 cm to 13.06 cm. Tree-stage individuals generally had diameters between 20.06 cm and 20.38 cm. These findings indicate that *D. celebica* has a strong capacity for natural regeneration, as demonstrated by the growth graph in Fig. 10.

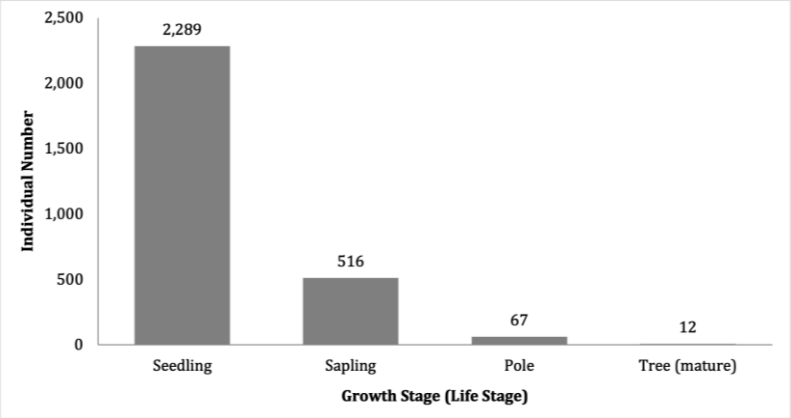


Fig. 10. Natural regeneration potential of *D. celebica* based on population structure diagram (Saleha & Ngakan, 2016)

Traditionally, population genetics studies rely on high-quality samples like leaves. Additionally, cambium or small pieces of fresh wood can be used in place of leaf samples. Therefore, innovations in sampling methods, such as using a Pickering punch to collect ebony wood cores in this study, are needed to enable multi-analyses that go beyond genetics, including isotope studies, near-infrared spectroscopy (NIR), anatomy, and chemical analysis (Siregar et al., 2022). In vitro culture technology enables rapid, large-scale plant propagation. Sterilization of plant explants is an essential step in tissue culture, as it removes microorganisms, prevents contamination, and supports explant growth (Tanjung et al., 2024).

Ebony is a slow-growing species, which makes it particularly vulnerable to extinction. Additionally, ebony seeds are recalcitrant, meaning they cannot be stored for extended periods. The optimal growth and physiological outcomes for ebony seeds were achieved with a 45% Penicillium microbial solution combined with seed coating. In contrast, the treatment without seed coating showed the best results with a 30% Sargassum microbial solution. Seeds soaked in microbial solutions tend to yield the highest success rates

(Larekeng et al., 2024). Furthermore, research on *Diospyros rumphii* using MinION Oxford Nanopore Technologies successfully generated high-quality DNA, facilitating species identification with rbcL markers and aiding future conservation efforts (Salindeho et al., 2023).

The ebony propagation strategy can also be carried out using microbes to accelerate ebony growth, such as a bacterial isolate that produces IAA and GA3, making it suitable for use as a biofertilizer (Lamanda et al., 2025). The colonization of arbuscular mycorrhizal fungi (AMF) in ebony roots is low, at 0.33% to 2.47%, with a spore density of 38–162 per 50 g of soil. Findings indicate that *D. celebica* is linked with fungal mycorrhizal associations (FMA), which can inform strategies to enhance cultivation, conservation, and restoration efforts (Yusran et al., 2023). Research on Macassar ebony (*Diospyros celebica*) has shifted from traditional morphological descriptions to the integration of genomic, metabolomic, and spatial modelling data. However, there is a persistent gap in the literature regarding the practical use of laboratory findings—such as antibacterial bacterial isolates or gold nanoparticles—in real-world industrial or conservation policy applications. More research on pathogen-microbiome interactions in natural habitats is strongly recommended to help ensure the survival of this endangered organism species.

4. Conclusions

A systematic review shows that Macassar ebony (*Diospyros celebica* Bakh.) is an endemic tree species of Sulawesi with very high economic value and has been designated the mascot of Central Sulawesi Province. This luxury wood is highly sought after in the international market for its heavy, strong, and durable qualities and distinctive grain patterns, such as *Batang Macis* strokes and *Sarang Laba-laba* strokes. Macassar ebony also has potential as a medicinal ingredient due to its bioactive compounds, including flavonoids and antidiabetic substances. However, despite its various benefits, the existence of this *Diospyros celebica* species is threatened by overexploitation rather than cultivation, primarily its slow growth rate. Its current conservation status is Vulnerable according to the IUCN Red List. As a result, the government's conservation efforts include both in-situ and ex-situ methods. Additionally, innovations such as tissue culture and propagation using microorganisms like bacteria and fungi can help accelerate growth. It is hoped that this review will encourage more serious and effective preservation efforts for Macassar ebony by various stakeholders.

The review literature reflects a shift in research from traditional descriptive-taxonomic studies to a multidisciplinary approach that includes Genomics and Biotechnology, utilizing *Next-Generation Sequencing* and Molecular Markers for genetic conservation. Green Nanotechnology involves using ebony biomass waste to synthesize advanced materials such as nanoparticles. Modern pharmacology has moved from traditional use to the isolation of pure compounds for treating diabetes and cancer. Climate ecophysiology focuses on understanding how species respond to global climate change to help reduce extinction risk. The main gap that still needs to be addressed is the lack of integration between omics data (genomics/metabolomics) and practical applications in tree breeding and the restoration of forest ecosystems at large.

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The authors declare no conflict of interest.

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During the preparation of this work, the author utilized Grammarly to enhance the manuscript's grammar, clarity, and academic tone. After using this tool, the author(s) reviewed and edited the content as needed and took full responsibility for the publication's content.

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