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REVIEW ARTICLE

AN INSIGHT INTO EBONY AND EBONIZATION OF WOOD

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ABSTRACT

Ebony, a dense black/brown hardwood coming from several species of genus *Diospyros*, is facing a scarcity in market due to trade ban. This constraint in material availability has led to the adoption of ebonization techniques in other wood, wherein wood is treated to mimic the distinctive dark black colour of ebony. Ebonization process has become an important factor in industries looking for imitated wood products to meet the consumer preferences for aesthetic appeal of ebony-like wood. In this paper a concise insight into the current status of ebony (*Diospyros ebenum*) in India has been given with emphasis on the ebonization. The paper reviews the effectiveness of various ebonization methods, with focus on the reaction of wood surfaces with iron salt, particularly iron acetate, as the most promising approach and challenges in this process.

Keywords: Black colour, coating, ebonization, *Diospyros ebenum*

1. INTRODUCTION

Ebony wood (*Diospyros ebenum*) holds significant importance due to its unique characteristics, historical significance, and use in carving. Since ancient times, *D. ebenum* is known for its jet black wood, and is regarded as the best commercial ebony (Hamalton *et al.*, 2021). It is a dense and dark hardwood known for its deep black or dark brown colour, and a highly prized wood due to its natural lustre, high density and luxurious appearance. It is also famous for its durability, and resistance to termites, fungi, and rot, thereby making highly sought wood for outdoor applications. Its ability to enhance the resonance and clarity of sound increase its demand for musical instruments. Its smooth carving and wood working makes it a priority species for artisans works of aesthetic appeal, which is often seen as status symbols. The main use of ebony is for its wood use in making musical instruments, ornaments, carved figures, gaming pieces, door handles, brushes, combs and billiard cues (Dahms 1990). In addition, it is used for making drum sticks, fingerboards, xylophones and wind instruments (Schmerbeck and Naudiyal 2018). Sahu and Das (2024) reported that Juang tribes of Keonjhar Odisha (India) intricate combs from ebony wood, primarily *Diospyros melanoxylon* Roxb. and *Diospyros ebenum* J. Koenig ex Retz with elaborate carvings depicting birds, flowers, and animals. These two species are predominantly traded from India. However, the latter is distinct as it produces a black wood devoid of any additional streaks or markings, setting it apart in terms of its unique quality (Gamble, 1922). Schmerbeck (2003) reported the use of young trees of *D. ebenum* for crafting knife handles at Bathlagundu in Tamil Nadu, South India. Further, he stated that the trees are harvested even at very small diameters; it's improbable that they form any significant heartwood. Ebony (*D. ebenum*), originally native to India and Sri Lanka, is traded under various names like Indian ebony, Ceylon ebony, ebony Mauritius, and ebony persimmon, reflecting its commercial significance. This species holds considerable economic value. Primarily exported to China for furniture manufacture and to Europe for luxury goods, ebony is a sought-after wood product in international markets (Kinho, 2014).

D. ebenum is locally called as 'Ebony', 'Karingali', 'Karu', 'Mushtambi', 'Vayari', 'Black ebony', 'Ceylon ebony', or 'Kari mara' in India and 'Kaluwara' or 'Karungali' in Sri Lanka (Wealth of India, 1953; Neginhal 2011; Jeyavanan *et al.*, 2016). In Kumta and Honnavar regions, it is most sought-after wood for carving purposes (Neginihal, 2020). IUCN status of this species is data-deficient for India and endangered for Sri Lanka leading to a ban on its trade in both the countries (IUCN 2007, 2013).

D. ebenum is a high demanding species as its wood availability in market is scarce. Due to less availability against high demand, overharvesting and habitat loss, some species of ebony declared are endangered (Meier, 2024). In India, the availability of ebony wood varies due to factors such as habitat loss, restricted logging, and conservation efforts. The trade and export regulations too have affected its availability due to which industries are shifting towards ebonized wood which is a general practice to darken the wood and offer it with appearance nearing the ebony. Darker wood colours due to its aesthetic appeal are gaining more popularity. Ebonized wood is often used in furniture making, cabinetry, decorative objects, and other wood items where the dark, rich look of ebony is desired. With this background, this paper reviews the general characteristics, status of ebony in India, and the process for ebonized wood so as to explore the existing knowledge in this area. The methodology involved thorough search of relevant recent literature on ebony and wood ebonization in Google Scholar, Google.com, Research gate, Wiley, Springer, Science Direct, etc. and other relevant data base. Additionally, the Section of *Diospyros ebenum*, Kerala Forest Research Institute (KFRIw 66) was referred to for gross wood anatomical features. The observations concerning ebonized wood in timber market were documented through inclusion of visual representations in the form of photographs.

2. STATUS OF *Diospyros ebenum* IN INDIA

Ebony belongs to the genus *Diospyros*, which comprises approximately of 400 species, primarily found in tropical regions such as Madagascar, Africa, and Malaysia, with two species native to the United States. Specific ebony species include Macassar ebony (*Diospyros celebica*) native to Indonesia, Ceylon ebony (*Diospyros ebenum*) native to Sri Lanka and southern India, and Gabon ebony (*Diospyros crassiflora*) native to western Africa (Martha *et al.*, 2021). Prasetyo *et al.* (2022) have documented the presence and distribution of other *Diospyros* species like *D. celebica, D. rumphii, D. lolin, D. ebenum, D. pilosanthera* and *D. ferrea* in African nations like Madagascar, Cameroon, Gabon, and Tanzania. Southeast Asia, notably Sri Lanka and Indonesia, also plays a significant role in global distribution of ebony. The historical trade routes also have played a pivotal role in facilitating the worldwide spread of this commercial important wood.

Across India, Deccan, Assam, Bengal and certain parts of Northern India host the distribution of predominantly over 40 *Diospyros* species (Hamalton *et al.*, 2021). Saraf *et al.* (2024) described the distributional shift of black ebony tree (*D. melanoxylon*) in India, and also illustrated the factors responsible for decreasing habitat. As per Neginihal (2020), a total of 25 species of *Diospyros* are reported from South India. Among these, *D. ebenum* is predominantly found in dry evergreen forests of the Deccan and Carnatic regions, where it is abundantly found on arid hilly slopes in the range of 250 to 1000 m masl. Its habitat extends from the Western Ghats to Coimbatore and southward to Tirunelveli. It is also frequently encountered in semi-evergreen to climax evergreen forests throughout the Ghats, especially in areas like Uttara Kannada, Belgaum (including Chorla Ghat, Dalzell and Gibson), Kumta, and Honnavar. They are especially prevalent in Dakshina Kannada, Hassan, and Shimoga districts, including the locations like Agumbe, Varahi, Chakra valleys and Teerthahalli (Neginihal, 2020).

Schembeck and Naudiyal (2018) reported the distribution of *D. ebenum* across the South India, particularly in the forest plains of Tamil Nadu and southern Karnataka, the Eastern Ghats, and the eastern slopes of Western Ghats. Earlier the occurrence of this species was noted in Andhra Pradesh (Cuddapah and Karnool districts) (Beddome, 1869; Brandis, 1906;), Orissa (Similipal National Park and Angul district) (Haines, 1922), Bihar (Munger district) (Sherwill, 1852), and Kerala, Assam, and Andaman & Nicobar Islands (Singh, 2005). Remarkably, the species thrives in a vast range of annual precipitation, from 750 to over 7000 mm, indicating its adaptability to diverse climatic conditions.

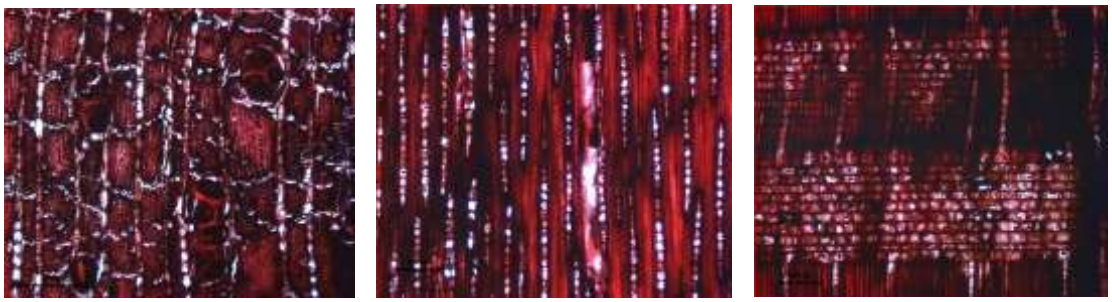
The species has been subject to extensive exploitation for its wood, which has likely influenced its current distribution and may have limited its spread in certain areas.

3. GENERAL CHARACTERISTICS OF EBONY (*Diospyros ebenum*)

Ebony's bole is straight, with buttresses up to 2 m high; crown dense, bark surface is scaly, fissured, black to grey-black (Vijayan *et al*., 2020). Due to dense foliage it produces dense shade throughout the year (Schembeck and Naudiyal, 2018). Mostly the tree is densely foliate, and crown is green and compact. The arrangement of leaves is alternate, the leaf shape is oblong to elliptic, mostly 6-10 cm long and 3-5 cm broad, thinly coaracious, glabrous, with rounded to acute base. The shape of apex is acute to obtuse with minutely reticulate veins. The petiole is about 0.5 cm long. The leaves are green and shiny in nature (Brandis, 1906; Mathews, 1983; Schembeck and Naudiyal, 2018). The species is dioecious in nature. The calyx of male flower is cup-shaped, measuring 3.0 x 3.5 mm, and glabrous with four indistinct lobes that are fringed and blunt. The flowers have 6-12 stamens, arranged unevenly, featuring 1.5 to 3.5 mm long filaments. The anthers are linear, extending up to 4 mm, with crested pointed connectives. Pistilodes are linear and can reach a length up to 2 mm. The female flower emerges individually from leaf axils and are supported by a 3 mm long pedicel. The calyx has four 4 mm long lobes, and are ovate, briefly fused, sub(acute) and widely spreading. The corolla is creamy in colour, has tabular form, measures 3 mm in diameter with tube length 6 mm and four acute lobes, each measuring 6 mm. The ovary is smooth, measuring 4.5 mm and features four styles and capitellate stigmas. Additionally, there are 6-12 staminodes present. The fruits are globose berries, exhibiting brief break at the apex and measuring 1.5-2.0 cm in diameter. The calyx shapes a shallow, woody cup and bends backwords. Each fruit possesses 3-6 dark seeds (Mathews, 1983; Schembeck and Naudiyal, 2018), measuring 10-13 mm in length and 2-5 mm in width at the posterior end, gradually narrowing at the front to 0-1 mm (Schembeck and Naudiyal, 2018). Field characters of *D. ebenum* are also defined by Neginihal (2020).

4. WOOD CHARACTERISTICS OF EBONY (*Diospyros ebenum*)

D. ebenum sapwood is light yellowish grey to grey in colour while heartwood is jet black, sometimes with streaks. It is very hard and heavy having air dry specific gravity of 0.96-1.12 with mean density of 1150 kg m^{-3} at 12% moisture level (Anoop and Pasha, 2018). It has fine even texture and smooth polished surface having straight grain to somewhat irregularly wavy (Nazma *et al.*, 1981). In terms of its anatomical gross features, it is diffuse porous wood having indistinct growth ring, small vessels, a few to moderately few, solitary or in radial multiples of 2 or 3 filled with brownish-black or black gum (Fig. 1). With respect to the drying behaviour, *D. ebenum* wood is liable to develop long fine deep cracks, if cut to wide sections, with average shrinkage of 5.5% in radial, 6.5% in tangential and 12% in volumetric sections (Annop and Pasha, 2018). It is easy to saw, and the work can be finished



A) Transverse section (10 x) B) Tangential section (10 x) C) Radial section (10 x)

Fig. 1: Anatomical features of *Diospyros ebenum* wood*:* A) Transverse section: Diffuse-porous, growth rings indistict, medium to large pores, solitary & radial multiples of 2-4; deposition in heartwood; Parenchyma fine undulating tangential lines forming reticulate structure. **B) Tangential longitudinal section**: Rays fine, uniseriate, closely spaced, intervessel pits alternate, **C) Radial longitudinal section**: Body ray cells procumbent with one row upright and/or square marginal cells; prismatic crystals present.

to a fine shiny smooth surface (Nazma *et al*., 1981); however, Anoop and Pasha (2018) elaborated wood working properties and noted that planning is slightly difficult in ebony; whereas boring and turning is easy thus leading to a good finish. It is a durable species but refractory to treatment.

5. EBONIZED WOOD

Genuine ebony wood is very expensive and difficult to source sustainably. Various wood species can be ebonized which include cherry, walnut, oak, ash, maple or any other light coloured wood, etc. Ebonization is a technique used to darken wood by applying stains or dyes to achieve an ebony like appearance (Thompson, 2023). This process is also applied to metals e.g. stainless steel and nickel plated mild steel. This approach offers a cost-effective way to achieve a similar aesthetic look without using genuine ebony. The methods applied by various researchers and other wood based industries for ebonization is enlisted in Table 1. Rolffs (1989) patented a method of producing synthetic ebony, wherein *Juglans* wood was treated with aqueous solution of iron salt having a concentration less than 18% by weight into the vessel, with vacuum therein. Steffanie Dotson, a furniture maker has created ebonized bamboo and ash-veneered desk with India ink (Dotson, 2015). Dagher *et al.* (2023) studied surface colour modification in white oak with the use of iron salts and its impact on the final appearance

Table 1: Some detail of ebonizing process in wood

S. No.	Method of ebonizing	Species worked on	Output	References
1	An aqueous solution of an iron salt having less than 18% by weight used with vacuum	Walnut (*Juglans* sp.)	A jet black product with bronze highlights similar to the colour of natural ebony	Rolffs (1989)
2	Alkaline treatment and iron-gall complex (black dye stuff) and ferrous sulphate as mordant for both dye solutions.	Poplar (*Populus nigra*) and pear (*Pyrus communis*)	Penetration depth of logwood dye was better than the gall treatment	Canevari *et al.* (2016)
3	Iron acetate by reacting steel wool and vinegar	Cherry and red oak	Maximal darkening with minimal application was attained by applying a 0.125 M iron acetate solution @ 1 mL 125 cm^{-2} wood surface	Thompson (2023)
4	Ammoniation	Oak, spruce and pine	Colour changes are mainly based on intensive darkening.	Weigl and Müller (2009)
5	Exposure to ammonia gas for 16 days	Oak, maple, spruce, and larch	Prominent darkening in oak, but not much changes in other species.	Miklecic *et al.* (2012)
6	Distilled vinegar and steel wool using the "liquid nightmare" approach	Oak hardwood floor	Wiping with a wet rag is that this raises the grain in the wood and finish depth is relatively thin.	Woodweb (2008)
7	Sand with fine-grit sandpaper, apply several coats of black paint and allow each layer to dry completely, use a cloth to lightly sand the piece and give it a smooth finish, seal the ash with a clear coat or wax to protect the finish.	Ash	Successful	Anonymous (2023a)
8	Iron acetate with tea and turmeric to supplement tannin content	Honey locust, oak, poplar, pine black cherry	Good result on honey locust, oak, black cherry	Anonymous (2023b)
9	A black dye used followed by a black stain	Ash	Achieved black colour	Mark (2016)

of wood, including its colour, grain contrast and surface roughness. The main reason behind colour modification is the reaction of iron salts with wood phenolic extractives. Canevari *et al.* (2016) studied two traditional wood-dyeing procedures carried out with iron-gall dye and iron logwood dye on two different wood species i.e. poplar and pear. In this study dyed samples were further analysed by means of FTIR spectroscopy, stereo- and polarized optical-microscopy and SEM-EDX. The reaction mechanisms reported for iron-gall and logwood inks as well as depth of penetration of dye was also well explained in this study. Darkening in wood was achieved by heat treatment method (Esteves and Pereira, 2009) as well as by ammonium treatment (Parameswaran and Roffael, 1984). In case of ammonium treatment, colour changes occurs due the modification of wood components such as hemicelluloses and various chemical interactions of wood extractives with gaseous ammonia (Weigl *et al.*, 2007). However, the colour intensity depends on the treatment duration and conditions. Weigl and Muller (2009) again studied ammonia treatment in oak, spruce and pine; and found ammonisation as one of the effective wood modification method to impart aesthetic value to wood. Ammonia fumes were experimented by Miklecic *et al*. (2012) on oak, maple, larch, and spruce. In oak, fumigation reduced the tannin content and subsequently changed the colour, however in case of other species tannin did not play any major role in colour changes.

Most of the research on ebonization was focused on use of iron base salts, because of the interaction between wood tannins and polyphenols with metallic salts, such as iron, resulting in the formation of dark brown and deep blue-black amorphous compounds (Thompson, 2023). The final colour may vary depends on the wood and the iron salt. The best results, in terms of black colour like ebony, was obtained with wood having high concentration of tannins (e.g. cherry, oak, walnut etc.) reacting with Fe(III) salt or Fe(II) salt that can undergo rapid autoxidation. The other methods of wood darkening involve dye or resin impregnation, where more intense colours can be achieved.

6. METHODS OF EBONIZATION

Among the reported methods of ebonization, the reaction of wood surface with iron salt (iron acetate) was found most effective in mimicking the desired colour. For this, first the wood surface is sanded and prepared to ensure a smooth and clean base for ebonizing treatment followed by the application of ebonizing solution to the surface (Rolffs, 1989; Hanlon, 2023; Thompson, 2023). Generally, for softwood like cherry, ash, oak, etc. the solution can be made by using vinegar and steel wool (Hanlon, 2023; Thompson, 2023). This solution needs enough time to react with the tannins present in wood. After that the wood is left to dry, allowing the ebonizing solution to penetrate and darken the wood fibres. After drying, wood finishers such as varnish, lacquer, or wax can be used to enhance its appearance and durability. In this process, the final colour can be different shades of black or brown depending up on the treatment process and duration. Additionally, there are many readymade products available in market under names like ebony wood stain, ebony black coatings etc., which also can be directly applied.

7. CHALLENGES IN EBONIZATION PROCESS

Ebonization is basically to mimic the natural ebony colour and present it as black as ebony, which has many practical challenge as below:

Inconsistency in final colour and replication: It is not easy task to achieve the colour like ebony in other wood. The primary issue in ebony is colour variation in wood surface. The final wood colour entirely depends on the chemical used and the treatment process followed including duration (Thompson, 2023). At lower concentrations, iron undergoes hydrolysis to form oxyhydroxide [Fe(III)OOH], which gradually transforms into grey-coloured magnetite [Fe(II)Fe(III)$2O_4$] (Jaen *et al.* 2003). This reduction process is associated with the oxidation of tannin phenol group. Further, the higher tannin concentrations result in the formation of darker and more stable iron–phenolate complexes thus leading to different colour outcomes depending upon the iron concentration used. The species having low tannin content need to use the dye or paint. However, in this case

modification of wooden surfaces without affecting its texture is difficult (Dagher *et al*., 2020). Applying a water-based solution causes the wood grain to raise, so require additional attention to achieve optimal finish (Rolffs, 1989; Stephens, 2016). Also, the reproducibility of ebonization methods needs standard protocol of treatment.

Compatibility with wood species: Different wood species respond in different manner to ebonization treatments, leading to some difficulties in achieving uniform coloration across the various types of wood (*https://www.projectguitar.com/tutorials/finishingrefinishing/ebonizing-wood-r37/*). Thus specie-specific characteristics are important for successful ebonization. Iron acetate gives better results in walnut and oak as compared to the mahogany, ash, sycamore, cherry, maple, pine, oak and beech, since later group forms varying grey shades or lighter colours instead of jet black. Dagher *et al*. (2020) found significant variations in final colour in wood species like white oak, red oak, sugar maple and yellow birch, which is attributed to the variations in phenolic content in various wood species. This revealed that same kind of treatment is not applicable to all wood species. Therefore, standardization of treatment methods for various wood species is a challenge. The treat-ment via reaction of iron based salt with tannin is also applicable to the woods having high tannin content.

Limited understanding of mechanisms: Despite the various ebonization techniques reported in Table 1, the mechanisms governing the colour formation and stabilization remain poorly understood. Though the reaction of iron-based salt with tannin and phenolic hydroxyls in wood is well understood (Dagher *et al*., 2020), the other aspects of the process are yet unlocked.

Long-term colour stability: The durability or longevity of artificial colour is another concern in ebonization process particularly in different environments with varying humidity and light exposure. So developing the methods to enhance colour permanence and resistance to fading is crucial. Some dyes/pigments are poor in light resistance, and prone to photo-degradation and leaching when exposed to UV radiation and rainy conditions (Hu *et al.*, 2020). There are significant differences in the colour stability among different dyes and the dyed species exposed to UV radiation and outdoor weathering, with some showing noticeable fading or colour change over time (Shao *et al.*, 2011; Baysal *et al*., 2014; Liu *et al*., 2015).

8. DIFFERENTIATING ORIGINAL EBONY AND EBONIZED WOOD

The real ebony (*Diospyros ebenum*) and the wood painted with black colour is shown in Fig. 2. One common method to identify the species-specific ebony is based on macroscopic and microscopic features, generally referred as wood anatomy. In case of *Diospyros*, this may be helpful up to genus level identification only, the species level identification is cumbersome (Jahanbanifard *et al*., 2019). However, it can be complimented with wood DNA barcoding. The anatomical features of *D. ebenum* is shown in Fig. 1. Sandratriniaina *et al.* (2022) studied anatomical features (interspecific variation) of 15 Malagasy *Diospyros* species to support the taxonomic revision of this genus at Madagascar and enriched the database for wood identification. They found significant intraspecific variations only in

Fig. 2: Original ebony (*Diospyros ebenum*) without any paints (left side); Wood painted black to mimic the black colour (middle and right hand side)

three *Diospyros* species (*D. gracilipes, D. squamosa* and *D. tropophylla*), mainly in terms of the number of groupings and density of vessels, which may further complicate their identification. While this scientific study is limited to the laboratory setting, the decisions for the general public are often based solely on physical features. Ebony is known for heavy weight and density of > 1 kg m^{-3}. Genuine ebony tends to have a more consistent and uniform black colour throughout the wood, while ebonized wood may have variations in colour that are usually indicative of its base wood. Scratching a small area may disclose the true wood colour under the surface.

9. CONCLUSION

Diospyros ebenum (Indian ebony) is known for its dark colour, fine texture and aesthetic appeal, making it a highly valued for use in furniture, musical instruments, and carving. Ebonizing avail alternative wood to genuine ebony and is a cost-effective choice for attaining a similar visual. It allows other wood species like oak, ash, or maple to resemble ebony in terms of colour and create a visually striking effect. However, the ebonized wood does not possess the same density, hardness, or other physical characteristics of genuine ebony. Research in this area predominantly focuses on the use of iron-based salts due to their interaction with wood tannins and polyphenols, resulting in dark brown and deep blue-black compounds. The alternative methods like dye or resin impregnation offer alternate methods for achieving more intense colours in wood darkening processes. The ebonization process face some challenges like inconsistencies in colour replication due to variations in wood species and tannin content, as well as limited understanding of underlying mechanisms governing the colour formation and stability, which require more research exploration. There is urgent need to standardize the treatment methods for different wood species as well as ensure long-term colour stability under various environmental conditions. Differentiating the original ebony and ebonized wood is a difficult task, which presently relies on assessing the factors like weight, density, and colour consistency, with microscopic analysis providing additional insight for species identification. Despite these challenges, advancements in ebonization techniques continue to offer alternatives to the scarcity of genuine ebony wood.

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