the production can be increased eightfold (considering 10,000 ha potential land), which is estimated to generate more than Rs 250 crores per year (Table 2). Along with the rush cultivation, other suitable programmes like fish farming, duck farming, cultivation of other wetland edible plants like *Neptunia oleracea*, *Colocasia cuculata*, etc. can be taken up. Cultivation of matting rush is a high income earning agro-practice. Cultivation and promotion of matting rush not only boost the economy and enhance employment opportunity, but also help in the conservation of wetlands.

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Use of timber in shipbuilding industry: Identification and analysis of timber from shipwrecks off Goa coast, India

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The use of timber in the boat-building or shipbuilding industry is as old as the construction of boats and ships. Various kinds of timber are used in different regions of India in the construction of vessels. The *Yuktikalpataru* (the wishing tree of artifice) composed by the king Bhoja of Dhar (11th century AD) gives a detailed account of boats, ships and the variety of wood used for construction and classification of ships. Further, the text also mentions the quality of timber that is required for construction of seagoing ships, which could resist the action of waves, currents and marine biofouling; above all, it would bring joy and wealth. In order to locate the remains of ships, cargo and their history, maritime archaeological explorations were carried out off Goa, which brought to light timber from the century-old shipwreck off St George's Reef and an iron anchor with a wooden stock 300 years old from Aguada waters. Radiocarbon dating and anatomical analysis of these two timbers were obtained to understand their age and to know the tree species. This communication details the anatomical analysis of timber and associated findings from the sites. Their tentative dates are ascribed to the findings in relation to the maritime history of the Goa region along the central west coast of India. Additionally, the study put forth the view that Indian teak was extensively used by Indian and foreign shipbuilders because of its high quality.

Keywords: Aguada Bay, iron anchor, shipwreck, St George's reef, timber.

INDIAN texts and archival records mention that seaworthy vessels of various types were built in India for overseas trade, commerce and naval warfare. Before the use of steel in the shipbuilding industry, timber was used extensively for construction of boats and ships. Panini (5th century BC) has mentioned that a large quantity of timber was used in construction of different parts of a ship[1]. India has a long maritime history, but there is a very little information available on the number of ships built, their purpose, history and other details. A number of ships are also known to have sunk due to various causes in Indian waters in the course of their voyages[2]. In view of this, maritime archaeological explorations were initiated in Goa waters in 1989 with the objective to explore and study the remains of shipwrecks, causes of shipwrecks, their period and provenance. Historical documents and archival records indicate that there were several wrecks off Goa, causes attributed to natural calamities like cyclone, collision against submerged rocks, reefs, sandbars, human errors and naval warfare[3]. Over the years, explorations have been carried out in Sunchi Reef, St George's Reef, Baga and Aguada waters along the Goa coast[4,5]. The explorations off Sunchi Reef yielded the remains of the Portuguese shipwreck datable to the early 17th century AD. Similarly, a century old shipwreck belonging to the Basel Mission Company has been explored off St George's Reef. An Admiralty Long Shanked type of iron anchor with wooden stock of the Portuguese period datable to the 16–17th centuries AD was retrieved from Aguada waters and from the north of Aguada, a pyramidal type of stone anchor was found off Baga waters (Figure 1). The study shows that ships could have wrecked off

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Sunchi Reef and St George's Reef on striking against the reefs or due to inclement weather.

Underwater exploration at a depth of 15 m off St George's Reef yielded various types of terracotta artefacts such as chimney bricks, roof, ridge and floor tiles, hollow column drum, a Corinthian-type column capital, drainage pipes and 2 m long timber of the wrecked ship. All these findings appeared as materials intended for house construction. 'Basel Mission Tile Works' 1865 is impressed on the bricks, roof and floor tiles. A detailed study of these materials shows that the company was actively involved in manufacturing terracotta artefacts in coastal Karnataka as well as Kerala and exported them to Africa, Australia, Borneo, Sumatra and other countries[6].

Archival documents mention that a number of ships have been wrecked at Aguada Bay during the Portuguese period because of the presence of sand bar in less than 3 m water depth. The sand bar has been referred to in the Portuguese hydrographic charts as *Barra de Agoada*. Underwater explorations were carried out by the National Institute of Oceanography (NIO), Goa in Aguada waters to locate shipwrecks as mentioned in the hydrographic charts. An iron anchor with 2.65 m long shank and 2.53 m nailed wooden stock was collected from the surrounding area of Aguada Bay. Shipwreck investigations yielded their remains which helped understand their period, provenance, etc. The finding of timber from the wrecks provided information on the quality of timber used in construction of ships and anchors during that period.

This communication is the outcome of detailed studies and anatomical analysis of timber found in the shipwreck off St George's Reef and wooden stock of the iron anchor at Aguada Bay. A comparative study has been made between these timbers, their state, name of species, dates and effect of woodborers on them. A brief account on the findings of the shipwreck off St George Reef and iron anchor at Aguada Bay has also been included.

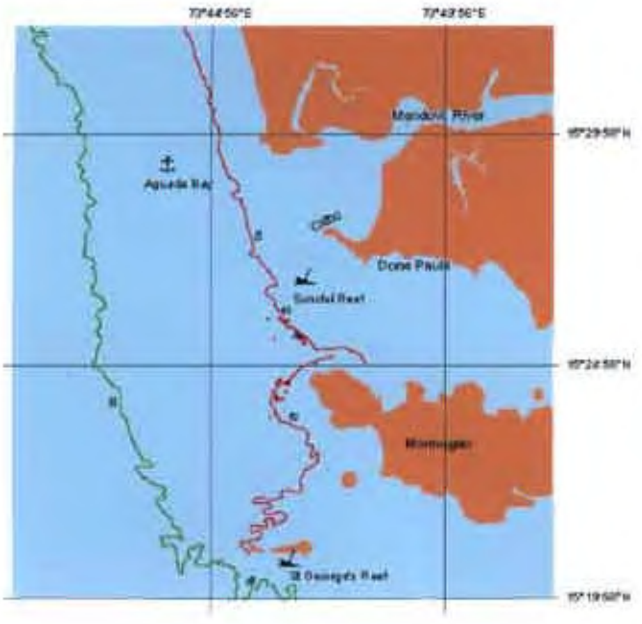

Figure 1. Location of sites mentioned in the text.

The materials used for the study consist of small uncarbonized and partially deteriorated wood pieces. Small blocks made from these samples were boiled in water and 20 μm sections (cross, tangential and radial) were cut on a Reichert sliding microtome. The sections were stained in haematoxylin and safranin and mounted in DPX mountant. The wood was converted into chips and macerated for observing individual elements according to Jane[7]. Sections were studied under Leitz Laborlux microscope connected to a Quantimet 500 MC Image Analysis System for anatomical characterization and identification. Prior to microtoming, the samples were studied for their physical features. The samples were also observed with and without hand lens (10X) to describe the wood, following Rao and Juneja[8]. The basis of identification of wood material was a combination of physical features, gross structure and anatomical characters. Photomicrographs were taken from the Image Analysis System[9,10].

Underwater exploration at St George's Reef yielded a large piece of timber lying close to the reef. The maximum length, width and thickness of the timber is 200, 18 and 16 cm respectively. The timber was partially buried in the seabed, probably soon after the ship had wrecked. Hence, it was not severely affected by current and wave actions. However, one end of the timber was affected by woodborers. The timber is U-shaped and longitudinal rabbets indicate that it could be part of the keel of the ship. The presence of iron nails shows that it was joined to other wooden planks of the ship (Figure 2). As the ship ran aground over the reef and broke into pieces, all the timber, light cargo and other organic material either might have been washed out or disintegrated subsequently. Radiocarbon dating of the timber shows that it is $114.3 \pm 1.5\%$ years old (measured radiocarbon age $T_{1/2} = 5570 \pm 30$ years)[6]. Anatomical analysis of wood indicates that it belongs to the *Lagerstromia microcarpa syn Lagerstromia lanceolata* species, for which the trade name is 'benteak'.

The state of the iron anchor from the Aguada Bay is good. It appears that the shank and half the portion of the wooden stock of the anchor, buried in the seabed, are intact and not affected by woodborers. The other half, which was above the seabed was greatly affected by woodborers. With the shank at the centre, nine iron nails have been used to join the wooden stock. Four of these nails have been used around the anchor shank and the remaining five have been provided on the other part of the stock. Only one nail is visible on the side affected by the woodborers, whereas the other four are in the intact portion of the wooden stock. No uniform distance has been maintained between the nails (Figure 3). A thick coat of yellowish cement mixture has been applied on the surface of the anchor and wooden stock except the iron ring, probably to protect the anchor from the marine environment. Microscopic observation of the coating material shows that sediments of mica and shell materials have been mixed with magnesium and calcium. This mixture becomes hard and does not dissolve in sea water; this could have been used as a protective layer for the anchor. The infrared spectrum (KBr pellet method) analysis (Figure 4) of the mixture carried out using a Shimadzu FTIR model 8201PC, shows the presence of organic substances on the anchor stock, which could be the deposit of marine organism belonging to a later period. Radiocarbon dating of the wood of the anchor stock suggests that the wood is 2500 ± 410 yrs BP; its calibrated age range is 2950–1950 yrs BP[11]. Anatomical analysis of wood indicates that it belongs to the *Tectona grandis* species for which the trade name is teak.

Any wood anatomist always looks at the specimen in terms of physical properties and also some of the attributes of internal anatomical structure. Further, the characteristics of any specimen are observed on cross, transverse or end-grain side, tangential longitudinal direction and radial longitudinal direction, both at macro level (gross structure) and micro level (minute structure) for description, which will ultimately lead to its identification.

Anatomical study of the wood samples shows that the wooden stock fixed to the iron anchor found in Aguada Bay is brown coloured, moderately hard, heavy and with medium texture. Its surface is soft-rot and soggy in nature. The gross structure of the wood shows that the ring is porous. Ring growths are distinct, conspicuous to the naked eye and delimited by large early wood vessels enclosed in parenchymatous tissue. Vessels in the early wood are visible to the eye, which is mostly solitary, oval in outline and gradually becoming smaller towards the late wood. Tyloses are present. Late-wood vessels are small, mostly solitary and round to oval in shape. Parenchyma forms thin sheaths around the vessels and it is distinct to the eye in the early wood. Rays are distinct under the lens.

The microscopic structure of the sample shows that vessels of wood are up to 285 μm in diameter, transition from early to late wood is gradual; intervascular pitting is alternate, 4–7 μm, vestured; vessel member length is 235–440 μm, tyloses are present and perforation plate is simple. Parenchyma paratracheal delimits the growth of rings. They are vasicentric and crystals are absent. Fibres angled in transverse section are not aligned in radial rows, septate, fibre diameter

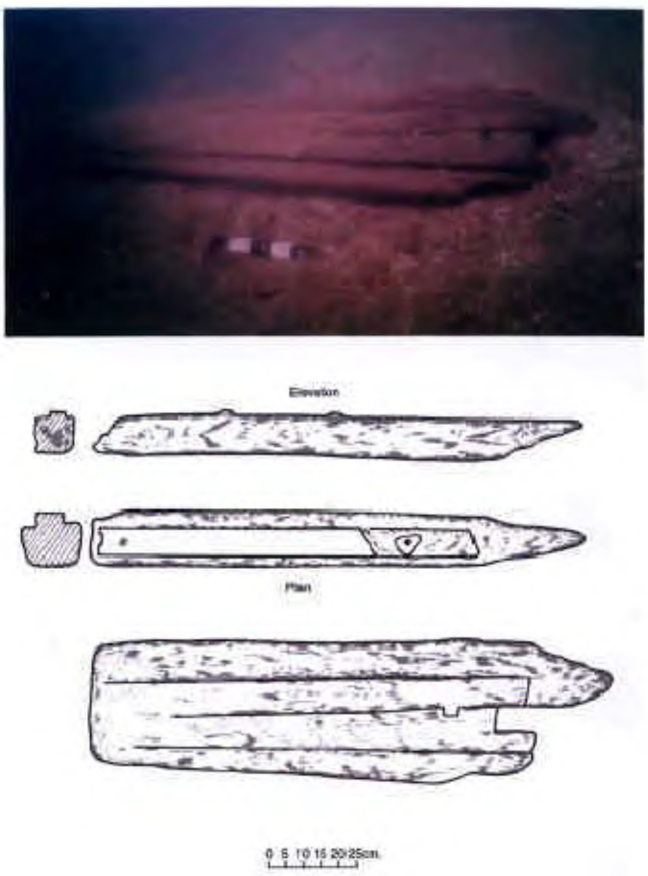

Figure 2. Timber remains of the shipwreck off St George's Reef.

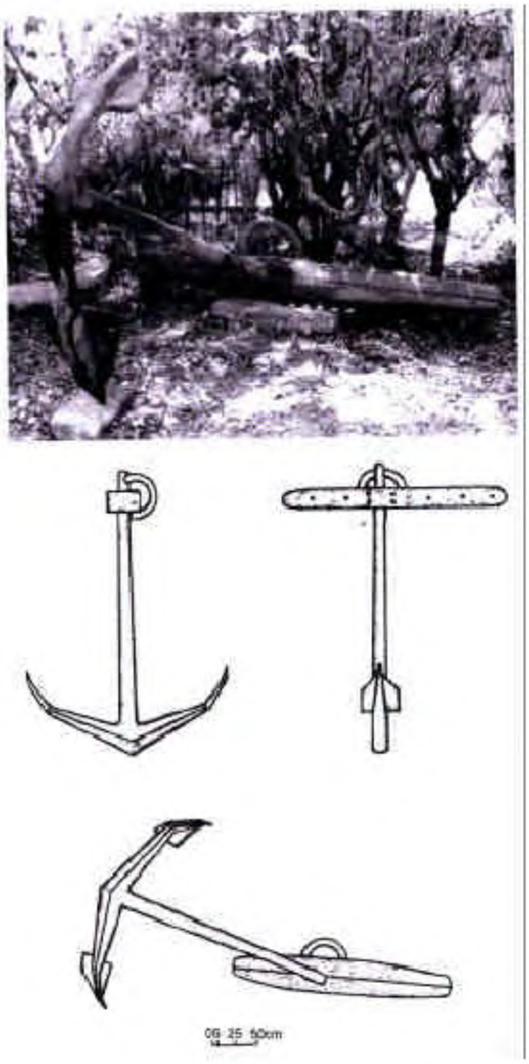

Figure 3. Iron anchor with wooden stock retrieved from Aguada Bay.

up to 32 μm, lumen diameter up to 25 μm, fibre length is 1027–1383 μm. Inter-fibre pits are numerous and confined to the radial walls. The macerated fibres showed extensive damage by soft-rot fungi, as evidenced by soft-rot cavities (Figure 5). This suggests that the material was exposed for sometime to wet and dry conditions prior to sinking. Rays 1–5 seriate, somewhat heterogenous, ray width is 77 μm and height is 20 plus cells or 688 μm. Silica is present. The diagnosis shows that the wood belongs to *T. grandis*.

The colour of the timber collected from the wreck off St George's Reef is brown, moderately hard, heavy and coarse in texture. Observation of the sample under hand lens shows that the timber has a darkened surface, which penetrates a few millimetres inside and is slightly soft. A few vessel elements indicate the presence of some non-woody materials. We suspect that they may be the remains of marine organisms.

Gross structure study shows that the timber is semi-ring porous wood, growth rings are demarcated by large early wood vessels and fine parenchyma bands. Vessels are solitary and in radial multiples of two. Transition from early to late wood is gradual. Parenchyma paratracheal vasicentric to aliform.

Microscopic structure study indicated that growth rings are demarcated by large early wood vessels. Vessels are 98–352 μm in diameter. Intervascular pitting alternate, oval, 7–11 μm, vestured, vessel element length 268–550 μm, truncate or tailed at one or both ends. Perforation plate is simple parenchyma paratracheal, aliform to aliform confluent and forming short bands. Moreover, crystals are present and fibres are rounded to angular, more or less radially aligned in cross-section. The fibre diameter is up to 32 μm and lumen diameter is up to 25 μm, fibre length is 1003–1479 μm, septate with several septa in each fibre. Interfibre pits are minute, simple rather sparse, confined to the radial walls. Rays are uniseriate, rarely biseriate, homogenous, ray width is up to 47 μm and height 15 plus cells or 340–638 μm (Figure 6). The diagnosis shows that the wood belongs to the *Lagerstromia* sp., probably *Lagerstromia lanceolata* for which the trade name is 'benteak'.

Numerous ships had been built for maritime trade in India, but no records are available about how long they were used, their abandonment and other details. However, one of the reasons why Alfonso de Albuquerque conquered Goa in AD 1510, was because of its shipbuilding industry[3]. During the Portuguese period, the shipbuilding industry in Goa reached its zenith. There were three dockyards in Goa between the city of Panaji and on the riverbank of Mandovi[12]. A number of ships were built in the Goa shipyard. Among them the important ones were *Nau Cinco Chagas*, *Galeao Bom Jesus*, *Madre de Deus*, *Nau S. Joao Baptista* and *Nau Cinco Chagas*. Before coming to India, the Portuguese used oak and pine for construction of ships. These ships were frequently affected by woodborers, crumbling due to weak timber, and maintenance cost of the ships was relatively high compared to their longevity. However, the native sailors used teak, which was the best timber ever known for shipbuilding industry in India. Subsequently, Portuguese understood the superiority of teak wood for construction of ships and used teak extensively in the shipbuilding industry. They established shipyards and dockyards in Goa for construction of ships. Teak was available in large quantities in the western coast of India, particularly in Kerala, Karnataka, Maharashtra and Goa. Portuguese as well as Indian boat-builders used readily available teak in the construction of ships and boats.

During the initial stages, the Basel Mission Company used bullock carts for transporting their products in the regional area. In the course of time, demand for the products increased, and as a result the company used native crafts on hire for the transportation of products throughout India[13]. The hiring of native crafts was cheaper and huge quantities of products were transported without hindrance. Tiles and other products were transported to Bombay (Mumbai) by native crafts and from Bombay they were exported to the British East Africa, Aden, Australia, Basra, Borneo and Sumatra[14]. The company also operated in other parts of the world, namely Ghana and China, but their industrial base remained the strongest on the western coast of India because of low investment costs and ready availability of manpower.

The Basel Mission Company used to engage wooden, sailing native crafts (with and without cabins) for transportation of the finished products, which is evident from the photograph[13] of AD 1910. Probably, they could be either *Kotia* or *Vana* type of crafts. Their sizes ranged between 8 and 10 m in length and had the capacity to carry about 30–50 tons. These crafts could sail close to the shore and the draught would be 2 to 2.5 m. The timber, found in St George's Reef, may have had similar dimensions. These vessels were predominant on the western Indian Ocean countries and were meant for transportation of cargo and local products.

The timber found in St George's Reef belongs to a craft, which could be smaller in size and locally built. This is because during the 19th century, the size of the European ships was much larger and bigger, especially when compared with the native crafts of India. Hence, it appears that the timber belonging to the craft could not have been of foreign origin and the probability of an Indian origin cannot be ignored.

Though it is difficult to state the provenance of the timbers found in the wooden stock at Aguada Bay and the single timber from St George's Reef, these timbers could be of Indian origin. This is evident from the fact that *Lagerstromia microcarpa* being a species of the Western Ghats and known for its use in boat-building industry, might have been utilized for the purpose from any of the localities along the west coast of India. Additionally, the boat-building and shipbuilding industry of India was known to mariners of the other countries since ancient times because of the availability of raw material. Also, the Portuguese had established a number of shipbuilding centres and dockyards in different parts of the west coast of India, namely at Old Goa, Thane and Bassein, because of availability of the good teak, which was cheaper, more durable and readily available to skilled craftsmen[15]. Therefore, the necessity to get timber from other countries did not arise. Some portion of the wooden stock has been affected by woodborers due to exposure to the marine environment, which could have happened subsequently. The timber lying underwater for several centuries has not decomposed, and in spite of exposure to the marine environment; this could be due to the quality of teak wood.

There are instances when ships built in Calcutta (Kolkata), India, namely *Sydney Cove* and *Valetta*, wrecked off Australia. The timber used in the construction of the *Sydney Cove* was teak (*T. grandis*), sisoo (*Dalbergia sisoo*) and Indian rosewood. The anchor stock of *Sydney Cove* was also made from teak[16]. Timbers used in the construction of the *Valetta* have been identified as teak; the report states that other local (Indian) wood and material were used in the construction, but could not be identified[17]. The Portuguese ship *Santo Antonio de Tanna* (1697), which was built at Thane, near Bombay and wrecked off Mombasa was also made of Indian teak wood found in the forest of Bassein near Bombay. Archival records related to the building of the ship were kept at Goa State Archives, Panaji and the writings of Portuguese naval experts, navigators and sailors of the time give other details about *Santo Antonio de Tanna*[18,19]. Similarly, *HMS Trincomalee* was built in Bombay in 1817 and the timber used was teak. *HMS Trincomalee* frigate served in the Royal Navy of the East India Company till 1897.

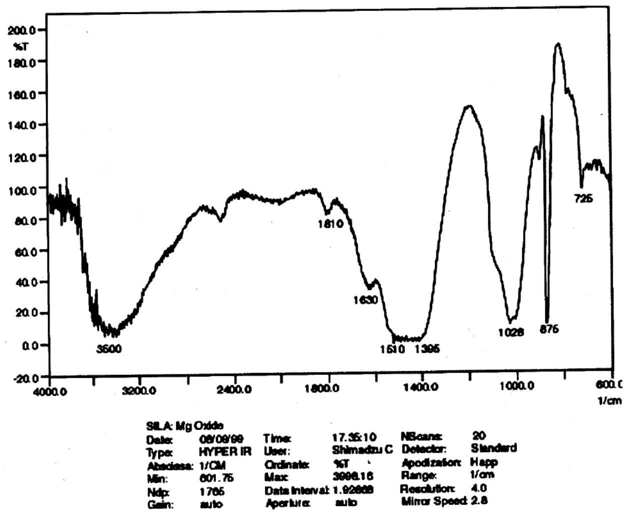

Figure 4. Infrared spectrum of coating material on wooden stock of iron anchor.

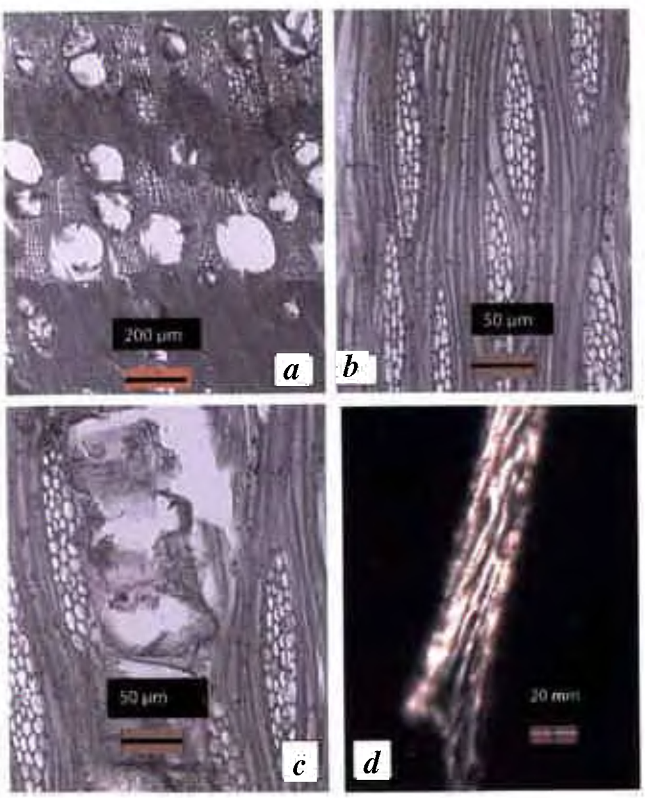

Figure 5. Anatomical analysis of timber of wooden stock from Aguada Bay. *Tectona grandis*. ***a***, CS showing ring porosity, parenchyma distribution. ***b***, ***c***. TLS showing ray morphology, intervessel pits and septate fibres ***d***. Fibre in polarized light showing soft-rot cavities due to fungal attack.

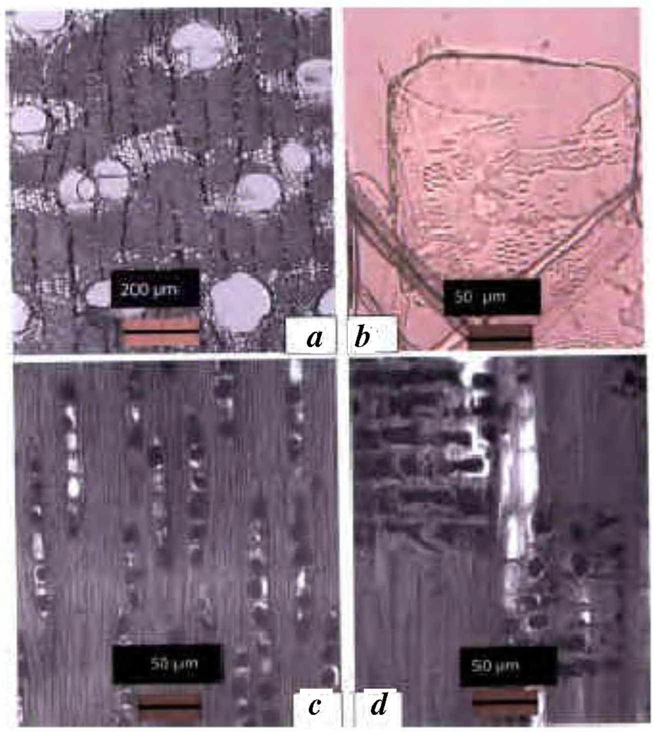

Figure 6. Anatomical analysis of timber collected from St George's Reef. *Lagerstroemia* sp. ***a***, CS showing vessels, diffuse and aliform parenchyma. ***b***, Maceration showing vessel element with intervessel pits. ***c***, TLS showing uniseriate rays. ***d***, RLS showing procumbent cells with deposits.

It was later refitted and renamed *Foudroyant* and subsequently sold[20].

Teak is one of the best timbers used for various purposes. The shipwrights industry also used teak in the shipbuilding industry for its superior qualities. Anatomical analysis indicates that *L. microcarpa* grown in the Western Ghats of India was used for building boats and ships. Indian as well as Portuguese shipwrights used both *L. microcarpa* and *T. grandis* species in the construction of ships. The timber off St George's Reef corroborates this.

The Portuguese understood the qualities of teak and used it extensively in shipbuilding industry and for various other purposes such as furniture, and house and church constructions. The East India Company also built several ships both on the east and west coast of India for the Royal Navy and overseas trade and commerce. Use of Indian teak for construction of ships by the Portuguese, British and Indian boatbuilders has been proved from the shipwreck findings in Indian and foreign waters. The use of Indian teak by Portuguese for making anchors is confirmed from the finding of the wooden stock of iron anchor at Aguada Bay. The use of teak for other purposes in the shipbuilding industry and its provenance could be known from the findings of shipwreck explorations in India in the coming years.

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Combined effect of gamma radiation and Azadirachtin on the growth and development of *Spodoptera litura* (Fabricius)

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***Spodoptera litura* is an economically serious and polyphagous pest in the Indian subcontinent. This pest is reported to attack a wide range of food plants belonging to diverse origin 112 cultivated food plants belonging to 44 families all over the world. In order to explore an eco-friendly strategy that could be coupled up with this radio genetic method, i.e., F-1 sterility technique, the present attempt was made to study the effect of a safe chemical (azadirachtin) for the effective management of lepidoteran pest, *S. litura*. The studies show that insecticidal toxicity can be altered if the insects are exposed to radiation prior to insecticidal treatment.**

Keywords: Azadirachtin, gamma radiation, *Spodoptera litura*.

THE efforts of man in combating agricultural pests by the use of toxic chemicals are frequently thwarted by the development of insecticide resistance by the insects, and/or by the establishment of new pests when predators and parasites

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