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Can African mahogany [*Khaya senegalensis* (Desr.) A. Juss] be introduced as a component of any agroforestry systems in India?

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Pradip Kumar Sarkar[1*], Bikash Das[1] and B.P. Bhatt[2]
[1]*ICAR RCER, Research Centre, Plandu, Ranchi, Jharkhand, India*
[2] *ICAR- Research Complex for Eastern Region, Patna, Bihar.*

African mahogany (Khaya senegalensis) is actually a fast growing timber trees mostly known for its multiple uses viz., timber, firewood, fodder, bark as medicinal, etc.. Being a fast growing species, it is having high potential in carbon sinks and thereby having the potential to reduce the rate of global warming and the resultant climate change. Moreover, it can be grown at varying ranges of soil, climate and topography. Hence, this species could be an ideal component of any agroforestry systems to achieve a win-win solution by inflowing into the carbon budgeting with nominal cost factor.

INTRODUCTION

African mahogany comprises of four different species *viz., Khaya anthoteca, K. ivorensis, K. senegalensis* and *K. grandifoliola.* Among all the species of this genus, the species *Khaya senegalensis* (African mahogany) is the most suitable indigenous species for timber production in the world, growing up to 35 m in high and 1.5 m in a diameter on fertile soil, with an 10-16 m clean bole, it's wood is hard, dense, reddish in colour and highly resistant to biodegradation. The wood has attractive colour, mostly straight grain orientation and a high luster (Egbewole *et al.,* 2017). It is one of the most economically important forest tree species which is very popular for timber and is used for high-class furniture making, joinery, building and construction purposes. This species is also known for having high traditional medicinal values and used as an ornamental tree for gardens and avenues in many countries. But introducing this species as a component under agroforestry systems in India is a matter of question. Furthermore, this species is a fast growing tree, grows well under varied soil and climate, and posses multiple uses; then why not to introduce them and use this species as an alternate to Indian mahogany as well as other species under agroforestry.

India is already having a total area of 328.72 M ha, out of which approximately 142 M ha areas are under cultivation, 69.79 M ha areas under forest cover (FSI, 2013) and approximately120 M ha areas are under degradation (FSI, 1999). All those degraded lands can be rehabilitated by means of planting trees "so called Multipurpose Tree species (MPTs)" (Shinde *et al.,* 2017; Sarkar *et al.,* 2019a; Sarkar *et al.,* 2019b; Shinde *et al.,* 2019) under agroforestry systems, which provide both tangible (Das *et al.,* 2016; Das *et al.,* 2017; Sarkar *et al.,* 2017c; Das *et al.,* 2019; Sarkar *et al.,* 2019c) as well as non-tangible benefits (Sarkar, 2019a), also helps in improving livelihood security by increasing the total productivity per unit area of land (Sarkar *et al.,* 2017c; Sarkar, 2019b). Hence, this *Khaya* species may find a place as a tree component under agroforestry systems in India. Moreover, there is very scarce information available on this species (*K. senegalensis*), even though it is seen to grow in many places in India *viz.,* West Bengal, Jharkhand, Chhattisgarh, *etc*.

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Ecology and distribution

The *Khaya* genus, belongs to Meliaceae family, is comprised of four species in mainland Africa but some are endemic to some places like Comoros and Madagascar. This genus belongs to sub-family *Swietenoideae* and most closely related to *Carapa* and *Swietenia.* The tree, *Khaya senegalensis* (Desr.) A. Juss, a deciduous evergreen tree (having chromosome number 2*n* = 50), belongs to Meliaceae family, commonly known as African mahogany, *Khaya* or dry-zone mahogany (Didier *et al.,* 2016). But this species is very close to *K. anthotheca* (Welw.) C.DC. and *K. grandifoliola* C.DC.

This *Khaya* species is a multipurpose tree species, but mainly it is grown for the timber purpose to suffice the demands of global wood markets. It is also an important fodder crop for cattle, provides wood for fuel and is believed to have important medicinal properties. The seed oil is rich in oleic acid which is used in cooking and in cosmetics (Arnold, 2004). The tree typically grows up to about 30 m in natural condition and has a wide crown, but under cultivation can grow even more than 35 m and attain diameters up to 1.5 m. Flowering in this species is mainly observed shortly before or early in the rainy season. The fruit apparently remains on the tree throughout the dry season, but when it gets ripen, the colour changes from grey to black. It begins to bear seed when the tree is 20-25 years old (Egbewole *et al.,* 2017). Moreover, it is reported as monoecious, insect pollinated and wind dispersed, with poor natural regeneration (Didier *et al.,* 2016).

The tree, *K. senegalensis* is native to twenty African countries *viz.,* Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Ivory Coast, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Mali, Niger, Nigeria, Senegal, Sierra Leone, Sudan, Togo and Uganda (Egbewole *et al.,* 2017) and occurs naturally within a seasonally-dry belt from Senegal-Guinea in the west to Sudan-Uganda in the east. It is a native species of Benin listed in Red list of IUCN as vulnerable and endangered in Benin red list (IUCN 2015-3; Didier *et al.,* 2016). It is rated as the tenth among the world's 20 most widely used and prioritized tree species suitable for development of forest industries and planted forests (FAO, 2014). It is also classified as vulnerable on the IUCN 2010 red list of threatened species (International Union for Conservation of Nature) because of overexploitation for timber, fodder, and medicine, and as a result of habitat loss and degradation (Nikiema and Pasternak, 2008). Efforts to restore the depleted mahogany resource can be possible if being introduced under plantation programme. Furthermore, this species can be grown in a wide range of altitudinal (up to 1800 m a.m.s.l.), climatic conditions (like varying rainfall range from 700 mm to about 1750 mm with dry season lengths of 2-8 months), edaphic and ecological conditions (Nikles *et al.,* 2008).

Uses of African Mahogany

This tree (*K. senegalensis*) is known to be a multipurpose tree having variety of economic and environmental values (Nikiema and Pasternak, 2008). It is considered as one of the major timber species in West Africa. It is also known for it's good quality red wood which is very hard and is having the resistance against fungus and termite. The timber is highly valued for carpentry, joinery, furniture, ship building, and as a decorative veneer. The bark is used in traditional medicine to treat malaria, diarrhoea, dysentery, anaemia, *etc*. Recently, the stem bark has been found to contain chemicals (limonoids) that exhibit antiproliferative activity against human cancer cell lines (Zhang *et al.,* 2007). It is also a good source of fodder for cattle, because of its high dry matter but relatively low crude protein content (Ouedraogo-Kone *et al.,* 2008) and is also a source of edible and cosmetic oils (Nikiema and Pasternak, 2008). In West Africa

and in many other countries (like South Africa, Egypt, Australia, Sri Lanka, China, Indonesia, Malaysia, India and Vietnam), the species has become an important urban amenity tree, commonly planted as a roadside or ornamental shade tree and also for the purpose of timber production (Arnold, 2004).

Bark, timber and firewood properties

The bark of this tree (*K. senegalensis*) is known to be medicinally important. It's extracts has the *in vitro* antiviral property. Even one experiment showed the *in vitro* antibacterial properties against stains of *Enterococcus faecalis* and *Streptococcus* sp. The same was reported to have property of exhibition of leishmanicidal activity. Earlier reports depict that the heartwood is mainly of pinkish brown, sometimes darkening to reddish brown with purplish tinge upon exposure but is distinctly demarcated from the paler, up to 8 cm wide sapwood especially in dry wood. The grain is usually interlocked, sometimes straight having moderately coarse texture. Wood density is reported to be varied up to 900 kg m^{-3} at 12% moisture content. While the sapwood is susceptible to trunk borer insect like *Lyctus sp.*. The heartwood is strongly resistance to impregnation but the sapwood is moderately resistant. The wood is also useful for firewood. The total energy value of firewood is reported as 19,900 kJ kg^{-1}(Nikiema and Pasternak, 2008).

Nursery management

Natural regeneration of African mahogany (*K. senegalensis*) from seed is poor as the seeds lose their viability after only two or three weeks under natural conditions. The viability of the seeds can be prolonged by drying to moisture content below 5% and storing them at a low temperature of around 5 ^{0}C (Egbewole *et al.,* 2017). Moreover, there is a major problem of mahogany shoot borer attack (*Hypsipyla robusta* Pyralidae (Phycitinae), which kills the main stem of young trees, causing excessive branching and contributing to mortality and poor quality timber production (Ky-Dembele *et al.,* 2011) that destroys the growth of plantations. Even, there was a report of causing leaf spot caused by *Alternaria argyroxiphii* (Teixeira *et al.,* 2017) and wilting caused by *Ceratocystis fimbriata* on *Khaya senegalensis* plantations in Brazil (Firmino *et al.,* 2017). Few studies reported that the fresh seed germinates readily after about 10 to 14 days with high germination rates (around 90%) when sown in a sand and peat mixed in flat trays. The seedlings can be picked out and grown in the nursery until they reach at a height of 25 to 40 cm. They should be planted into the field just after the onset of monsoon (Nikiema and Pasternak, 2008). Another method of planting stock is to use striplings or wildlings (Egbewole *et al.,* 2017), which are of small sized seedlings of about 40 to 50 cm in height having pencil thickness diameter, growing at the base of large mature trees. During the wet season, individual seedlings can be pulled out of the ground and, after stripping the leaves and pruning the root section, they can be planted directly into the field after sufficient rain, or potted in containers.

Khaya senegalensis grows in a wide range of soil types (Didier *et al.,* 2016). The pH tolerance can range between neutral to very strongly acidic; however, a neutral pH is more desirable (GFRA, 2005). It prefers well-drained soils. Sandy loams are ideal, whereas poorly-drained clays or duplex soils should be avoided. It should not be planted in shallow soils as this will prevent the large taproot from developing and anchoring the tree. One experiment revealed that potting mixture composition of vermicompost and red soil in the ratio of 1:1, resulted in maximum seedling growth in terms of height, collar diameter, root length, number of leaves and seedling biomass at 120 days after sowing, followed by T5 (Sand: Red soil: FYM of 1:1:1) and T7 (Neem cake: Red soil of 1:1

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ratio) in *Khaya senegalensis* (Sondarva *et al.,* 2017).

The vegetative propagation using leafy stem cuttings has been successful (Ky-Dembele *et al.,* 2011) in African mahogany (*K. senegalensis*). An experiment conducted in Thailand revealed that hedge height of *Khaya* at 20-30 cm from root collar provided greater rooting percentage than 30-50 cm, while cutting position (top, middle, and proximal section of the stump) had no significant effect on cuttings rooting capacity. Moreover, various grafting methods like Chip budding, cleft grafting, and side-veneer grafting have been successfully used for *K. senegalensis* seedling grafting in Burkina Faso (Ou´edraogo, 2004). But, micro-cuttings had also been successfully applied to micrografted plants with scions collected from 6-year-old trees of *K. senegalensis* (Brunck and Mallet, 1993). Another study reported that, leafy cuttings rooted well (up to 80%) compared to leafless cuttings (0%). Even, the cuttings taken from seedlings rooted well (at least 95%), but cuttings obtained from older trees rooted maximum upto 5% (Ky-Dembele *et al.,* 2011). The rooting ability of cuttings collected from older trees was improved (16% maximum) by pollarding. On the other hand, the plant growth hormones like auxin application enhanced the root length and the number of roots, while other treatments like smoke solution did not improve cuttings' rooting ability.

In another experiment of *In vitro* shoot multiplication, Danthu *et al.* (2003) reported that the rooting of micro-cuttings was successful in a less concentrated medium (MS/2) and a weak auxin concentration (IBA 5.2 µM) or by a 1- to 7-day long induction on a medium with IBA 260 µM, followed by transfer to a regulator-free medium. A method of micro-grafting of *K. senegalensis* was also developed, where grafting of apices or buds taken from young shoots onto the epicotyl of young seedlings grown *in vitro* was done.

African mahogany as agroforestry component

In many other countries, this tree is grown as a main crop either in solitary or in mixed system. One study revealed that, *Khaya senegalensis* saplings intercropped with cassava at agroforestry plantation plot had attained a maximum height, basal girth, diameter at breast height and leaf count within a period of 36 months of planting on the field while compared with monocropping system (Egbewole *et al.,* 2017).

In contrast to African mahogany, there is another species like Indian mahogany (*Swietenia macrophylla* King) of the same family, which is in common use under agroforestry systems in India for timber purpose. But under field condition in one trial during 2015-19, conducted at ICAR-Research Complex for Eastern Region, Research Centre, Plandu, Ranchi, the growth of African mahogany (*Khaya senegalensis*) was found far better than Indian mahogany in all aspects *viz.,* tree height, girth, canopy spread, crown height, *etc*. Hence, African mahogany can act as a best alternate substitution of Indian mahogany and many other species as a tree component under agroforestry systems in India and can integrate with other crops and/or animals for crop diversification (Kumar *et al.,* 2016).

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African mahogany based agroforestry model (3 years old) at ICAR RCER, RC, Ranchi

Carbon sequestration potential

Sathaye and Ravindranath (1998) reported that an agroforestry can be sequester of an average of 25 Mg C ha^{-1}, but there are differences in biomass production in different regions of the country and hence, variations do exist in carbon sequestration too (Sarkar *et al.,* 2017a; Sarkar *et al.,* 2017b; Sarkar *et al.,* 2017c; Sarkar, 2019a; Sarkar, 2019b). Moreover, the fast growing tree plantations are considered to be highly efficient in carbon sinks and having potential to reduce the rate of global warming and the resultant climate change (Sathaye and Ravindranath, 1998; Sarkar *et al.,* 2017c), largely contributing to climate change mitigation. Among all the fast growing existing trees, African mahogany is reported as one such example for good carbon sink in tree itself (Warnasooriya and Sivanantharwer, 2015). A study reported that, greater biomass of African mahogany at tree level was recorded for many age classes in Kurunegala division of Sri Lanka attributing to moisture rich growing conditions, while less annual rainfall and prolonged drought resulted a significantly lower tree level biomass grown at Anuradhapura divisions of Sri Lanka. The average above ground carbon sequestration of *Khaya i.e.,* 88.98 and 127.92 tonnes per ha in Anuradhapura and Kurunegala divisions of Sri Lanka were well ahead of the IPCC's benchmark of plantation forests in 'Tropical Dry' climate *i.e.,* 30 tonnes per ha, indicating its potential of climate change mitigation, besides the timber use (Warnasooriya and Sivanantharwer, 2015). The total amount of carbon sequestered by existing *Khaya* plantations amounted to 21,785.25 and 27,969.10 tonnes in Anuradhapura (741.92 ha) and Kurunegala (475.20 ha) divisions, respectively.

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CONCLUSION

African mahogany (*Khaya senegalensis*) is actually a fast growing timber trees mostly known for it's multiple uses. Moreover, it can be grown at varying ranges of soil, climate and topography and having the high potential in carbon sinks. Hence, this species could be an ideal component of any agroforestry systems to achieve a win-win solution by inflowing into the carbon budgeting with nominal cost factor.

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