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A Vital Medicinal Trees *Khaya senegalensis* (Desr.) A. Juss. and *Khaya grandifoliola* C.DC., Native to African Savanna Region: Study of the Interspecific Variation in Morphology, Seeds Germination Characteristics, Early Growth Development of Seedlings and Ethnobotanical Indices

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ABSTRACT: Species of *Khaya* are exotic to Sudan and overexploited for its valuable wood and ethno-medicinal values. The study aimed to provide scientific and up-to-date data about commonly known species *khaya senegalensis* and *Khaya grandifoliola*, with special reference to their morphology and growth development at mature and seedlings stages, suitable seed germination techniques as affected by pre-sowing treatment methods and seasons. Materials were collected from established plantations in Abu Geili riverine forest reserved (13° 34' 41.51" N; 33° 35' 20.08" E) in Sennar state, Sudan. 10 trees (mature, dbh 25-30 cm) were randomly sampled in spacing not less than 100 m apart, and surveyed during time of vegetative growth (June-October), fruiting and seeding (March-May) for data collection. Morphological characterization for each species assessed by evaluating 17 vegetative traits (11 Quantitative, 6 qualitative), 13 fruits' traits (8 quantitative, 5 qualitative) and 11 seeds' traits (9 quantitative, 3 qualitative). Analysis of variance performed to compare between the studied species (Ks and Kg). Germination experiments conducted during summer, autumn and winter and laid in completely randomized design with 4 replications using 6400 seeds (3200 seeds each species), and . The seeds per species (3200) were tested for germination under four pre-sowing treatments (800 seeds each treatment): i.e. immersion in hot water (100 °C, cooled overnight), cold water (4 °C, 24 h), and concentrated sulphuric acid (5 min) followed by soaking, in addition to untreated as control. The seeds were sown in polythene bags (10 seeds each), and monitored a nursery under controlled conditions, and germination indices (percentage, germination rate index "GRI", mean germination time "MGT"), and shoot and root morphological characteristics and development at early ages were

recorded. The data were analyzed using ANOVA (GLM, SAS v9.0). Significant differences ($p = 0.0001$) between species were observed in morphology at maturity Ks had the highest measures for leaflets number per leaf, while Kg had the largest leaves' dimensions, as well as fruits' and seeds' dimensions. For both Ks and Kg, pre-sowing treatments significantly improved germination during different seasons (autumn, winter and summer) compared with controls. The highest germination success obtained during autumn season (July-October) from hot water treatment (80 °C for 10 min) 94% for Ks and 92% for Kg; followed by cold water (37 °C) treatment overnight 92% for Ks and 90% for Kg. Less success across all pre-sowing treatments was recorded for both species during winter season (December-February). Varying seedlings growth performance in roots' and shoots' morphological characteristics was reported between Ks and Kg. These savannah species Ks and Kg are native to Africa, this study highlighted its possibility to germinate by seeds in wide range of pre-treatment (tap water, hot water and cold water and H₂SO₄), and in different growing seasons (autumn, summer). In addition, the better growing performance and development from early seedling stage up to maturity indicates their adaptive potential to grow in different area and changing climates. These results are decision support tools for the regeneration of multipurpose, exotic forest species such as Ks and Kg that have high agroforestry potential, socio-economic importance and suitable for ecosystem restoration.

INTRODUCTION

Genetic variation is the basis of the breeding program of plants (Ali, 2023). Genetic diversity of plant species is vital since it widely be used in the management, conservation, breeding, and creation of living vegetation (Ali, 2023; Ouborg, 2010; Ghazaeian, 2015). Determining the genetic diversity in plant materials is of great importance and is the first and fundamental step to identifying, preserving, and maintaining the genetic resources, which are considered the basis for genetic research and breeding programs (Ali, 2023). Morphological characterization among several methods is the most powerful method to determine genetic diversity and classification of plants for agricultural benefits (Jannatabadi *et al.*, 2014). Morphological traits were the earliest markers used in plant taxonomy, germplasm management, and breeding programs (Gibreel *et al.*, 2024). Morphological classification is a useful guide to identifying species relationships and increases the knowledge of plant breeders and gene bank managers (Ali, 2023). Moreover, knowledge of the relationships between plant traits (regression and correlation relationships) is useful for plant breeding and development of floras (Ouborg, 2009). Morphological characterization of plants using morphological traits is also, one of the first steps to identify genetic resources. However, they have several limitations, including low polymorphism, low heritability, late expression, and vulnerability to environmental influences (Beyene *et al.*, 2005) particularly the quantitative traits (Govindaraj *et al.*, 2015). The vegetation cover and natural forests in the subtropical arid and semiarid regions are changing and losing their capacities for natural regeneration (Elobeid, 2000; Gibreel *et al.*, 2013). Since, the seeds of any plant species is a link between the evolutionary processes of the past and the potential for future adaptation (Gibreel *et al.*, 2019), the seeds of many native and exotic species are challenging to germinate (Vozzo, 2002). Therefore, many pre-sowing techniques have been developed, studied and adopted to overcome seeds dormancy and increase or enhance germination percentage for a diversity of seed types (Aboutaleb *et al.*, 2012; Gibreel *et al.*, 2019). Urban forests have been around for generations but only recently have they become valued for providing more than aesthetic and recreational values (Mohamed *et al.*, 2019). Cities around the world now regard trees and other vegetation as critical urban infrastructure as important to how a city functions as roads or public transport and particularly vital to the health and wellbeing of communities. The benefits of urban forests span whether environmental, economic, cultural, political domains, are interrelated with each cumulatively, and feeding into the creation of resilient and sustainable urban landscapes (Mohamed *et al.*, 2019). In Sudan, there are many exotic species with high potential roles in urban forestry, horticulture and agroforestry, but few is known about their silviculture (Osman *et al.*, 2026). However, most urban trees distributed on the roads, in front of and inside houses, governmental institutions and parks (Mohamed *et al.*, 2019). Effective propagation and plantation success of potential exotic multipurpose tree species for urban and rural afforestation in Sudan depend largely on understanding their fruits and seed characteristics, as well as factors influencing germination and early growth development (Osman *et al.*, 2026). *Khaya* (called African mahogany) is

a genus in the mahogany family Meliaceae, native to tropical Africa with five tree species (*Khaya anthotheca* (Welw.) C.DC., *Khaya ivorensis* A.Chev., *Khaya adagascariensis* Jum. & H.Perrier, *Khaya senegalensis* (Desr.) A.Juss., and *Khaya grandifoliola* C.DC.), distributing across various countries from Senegal to Sudan to Uganda, as well as Madagascar (Govaerts *et al.*, 2021). In the Sudan, the genus “*Khaya*” is well known by two species reported as exotic species in Sudan’s floras (El Amin, 1990; Darbyshire *et al.*, 2015); these were *Khaya senegalensis* (Desr.) A. Juss. (called Mahogany Arid Al Safaga in Sudanese Arabic) and *Khaya grandifoliola* C.DC. (called Mahogany Arid Al Safaga in Sudanese Arabic). However, *Khaya senegalensis* (Desr.) A. Juss., is grown and managed as Urban forestry species mainly in avenue and roadside trees all over the country; while. *Khaya grandifoliola* is not widely distributed in the Sudan, and only recognized as scattered individuals in Abu Geili riverine reserved in Sennar State (latitude 13° 34' 41.51" N., and longitude 33° 35' 20.08" E.) within low rainfall Savanna zone in Sudan.

Khaya senegalensis locally known as Mahogany is one of the most popular, economically important and multipurpose forest tree species, used for high-class furniture, joinery, building and construction purposes, and recommended for utilization purposes for which surface quality is of high importance (Zaccheus *et al.*, 2018). The species has also high traditional medicinal values and used as an ornamental tree for gardens and avenues (Obafemi *et al.*, 2015). Traditional healers in Western Cameroon use the stem bark of *Khaya grandifoliola* for the treatment of malaria and salmonellosis (Bickii *et al.*, 2000; Kodjio *et al.*, 2020). From field surveys and observation it clear that, the species of *Khaya* in Sudan can grow in a wide range of habitats extend from Semi-desert in the north to low and high rainfall savanna regions, and produces high amount of quality fruits and seeds, and know data available about the productivity per tree or an area. Moreover, heavy pruning of branches by local communities or stripping of bark for traditional medication and/or fodder uses significantly reduces the tree’s productivity output and fruit count being impossible and need more consideration. These two species are in danger of extinction, since they overexploited for its valuable wood and medicinal values of its different parts, particularly for local people and healers who believe on the medicinal activity of its bark and leaves in particular as therapeutic extracts in traditional medicine against some human and animal diseases. In addition, researches related to their vegetative and reproductive morphology, silviculture management, seeds germination technology and treatments as well as early growth development of natural seedling at nursery stage not well documented in the Sudan. The regeneration and the successful integration in tree nurseries, as well as for the direct plantation in arid and semi-arid lands, requires the understanding of the aspects of seeds treatments (Kheloufi *et al.*, 2017). Seed problems related to seed dormancy often limit the use of particular species in nurseries for the production of seedlings; it is because seed dormancy can vary from species to species, stage of maturity of seed and degree of drought and consequently pretreatments should be adjusted accordingly (Azad *et al.*, 2012). Therefore, the sustainable management of *K. senegalensis* and *K. grandifoliola*, necessitates more silvicultural attention, especially in light of climate change and illegal exploitation of trees outside reserved forests, such as those growing in urban areas through adoption of regeneration techniques and assessment of the degree of morphological variation that reflects their adaptation to the changing climate. More and above, there is little information available on their germination and early growth amongst many others indigenous and exotic tree species which makes it a bit difficult to make informed decisions in determining their potential use for plantation establishment, agroforestry and other forestry activities. Therefore, the study aimed to provide up-to-date data on phenotypic characterization and the degree of interspecific variation in morphological characteristics, seeds germination characteristics and early growth development of seedlings at nursery level, as well as ethno-medicinal values among *Khaya senegalensis* and *Khaya grandifoliola*, a multipurpose and promising exotic tree species for Sudan’s urban afforestation programs.

MATERIALS AND METHODS

1. Description of the study area

The study was conducted during 2023-2025 in Abu Geili Riverine Forest Reserve (registered with Gazeta No. 1, August 18, 1940), in Sennar State, Sudan. It lies in the eastern bank of the Blue Nile River, at far distant of about 10 Kilometer north-west Sennar dam, geographically between latitude 13° 34' 41.51" North and longitude 33° 35' 20.08" East, and average altitude of 420 meters above sea level (Gurashi, 2024). The forest occupies an area of 338.94 hectares of which 152.04 hectares Gerif land, 158.76 hectares low land (Mayaa) and 28.14 hectares upland (Karab site). The study area characterized by the climate of the low rainfall Savanna woodland (Harrison and Jackson, 1958), where April (32°C) and May (30°C) are the hottest months, and December and January are the coldest; relative humidity is low in March and April (30%) and reach 78 % in August (Gurashi, 2022). The average annual rainfall of the state is 450 mm. The soil of the forest is mostly hard cracking clay, and a mantle of alluvial soil is covering the area adjacent to Blue Nile banks. The vegetation cover of Abu Geili forest is dominated by *Acacia*

nilotica in pure stand on the flood basin in the northern part, other species raised at the southern part of the forest mainly *Eucalyptus camaldulensis* E. *microtheica* and two species of the genus *Khaya* (*senegalensis* and *grandifoliola*). Within the Eucalyptus plots, species trails plots of *Sclerocarya birrea*, *Albizzia lebbek*, *Dalbergia melanoxylon*, *Moringa oleifera* and *Cordia africana* were established. The forest have a small nursery and a small garden of mango trees, and a few bamboo clumps are found at the river bank. *Faidherbia albida*, *Calotropis procera*, *Maytenus senegalensis*, *Boscia senegalensis* and *Cordia rothii* are present with other species in the Gerif land. The area within the forest and outside the basin “Karab site”, is dominated by *Balanites aegyptiaca*, *Capparis deciduas* and *Acacia seyal* (Gurashi, 2024).

2. Data collection procedure

Species identification and sampling procedure

The trees of *Khaya senegalensis* (KS) and *Khaya grandifoliola* (KG) were identified using published taxonomic key and written description (El Amin, 1990). The random tree sampling procedure was adopted (Abdelkheir *et al.*, 2011; Gibreel, 2015 and Osman *et al.*, 2026), by selecting 10 mature individuals (dbh 25-35 cm) in spacing not less than 100 m apart, and marked for further data collection. Time of vegetative growth (June-October), fruiting and seeding (March-May) for each species in the Sudan considered during field surveys and data collection (Salih *et al.*, 2021).

Morphological characterization of mature trees (habit and vegetative parts)

The selected trees “10 for each species” measured for its height (m), dbh (cm), crown diameter, the tree habit and the texture and color of the main stem were also evaluated. In total, 15 mature branches (20 cm long), were harvested from the crown (bottom, middle and possibly top) of each single tree and used for morphological characterization of vegetative parts (Gibreel *et al.*, 2024). The quantitative evaluations included the number of compound leaves (in pairs), leaf length (cm), petiole length (cm), number of pinnae's (in pairs) per compound leaves, pinnae length (cm), pinnae width (cm), number of leaflets (in pairs) per pinnae, leaflet length (cm), and leaflets width (cm). Other qualitative evaluation comprised leaflet color, leaflet shape and surface texture. All micro-measurements were made using 150 mm-digital vernier caliper (Modle: GT-DC-01, Globaltronics GmbH & Co. KG), and photographs were taken by using a Canon digital camera (Canon 1300D, JAPAN).

Morphological characterization of reproductive parts (fruits and seeds) of mature trees

The reproductive parts characterized using 100 ripe fruits “capsules” were harvested from top, middle and bottom of the tree’s crown (Gibreel, 2015; Osman *et al.*, 2026) and weighted by using sensitive balance to determine the weight of 100-fruits in gram. The capsules were quantitatively measured for length (cm), width (cm), thickness (cm) and its entire number of seeds were counted, and seed’s dimension (length, width and thickness in cm) was measured and weight of 100-seeds was determined. The weight of 100-fruits “capsules” and 100-seeds used in calculation of their number per kilogram (Equation 1 and 2). The qualitative evaluation of the vegetative parts (capsules and seeds) included shape, color and surface texture. Fruits production per tree (Kilogram/tree/year) was determined in two seasons 2024 and 2025 following the procedure adopted by Osman *et al.*, (2026), by harvesting and weighting in kilogram all capsules (as possible) produced in the crown of 4 trees selected randomly for each species.

Equation 1: Number of capsules per Kilogram = $([1000 \times 100 / 100\text{-pods weight “g”}])$

Equation 2: Number of seeds per Kilogram = $([1000 \times 100 / 100\text{-seeds weight “g”}])$

Effects of pre-sowing treatments on seeds germination and germination indices

The seeds extracted from 100 capsules selected randomly for each species from the harvested one. The extracted seeds tested for viability by using floating technique (Ahmadloo *et al.*, 2011 and Gibreel *et al.*, 2019) and purified by discarding and eliminating damaged, insect infected and empty seeds, and stored in clean polythene bags for further use. The germination experiments were conducted in three seasons during summer (April-May), autumn (July-October) and winter (December-February), in completely randomized design with four replicates. In total, 6400 seeds were used for *K. senegalensis* and *K. grandifoliola* (3200 seeds each), and subjected to 4 pre-sowing treatments in four replicates each treatment (200 seeds each treatment and replicate). The pre-sowing pretreatments included soaking in hot water (100°C) and kept to cool overnight, soaked in cold water (4°C) overnight, and soaked in concentrated H₂SO₄ “sulphuric acid” (98% H₂SO₄) for two minutes followed by washing and soaking overnight in distilled water and control was untreated seeds (Edward *et al.*, 2013; Gibreel *et al.*, 2019). Seeds for each species to

each 4 treatment and 4 replicates (3200 seeds), were sown 320 polythene bags (20x25 cm) prepared as sown unites by mixture of clay and sand (2:1), with rate of 10 seeds per polythene bag and monitored at controlled nursery condition and irrigation regime of three days interval. The number of germinated seeds (the emergence of cotyledon and 2 mm radicle through the seed coat) was counted (Kheloufi *et al.*, 2017; Gibreel *et al.*, 2019) for 60 day after sowing and final germination was expressed as percentage “G%” (Equation 1). Further germination indices as considered and adopted by Gibreel *et al.*, (2019) were the germination rate index “GRI” bwhich reflects the percentage of germination on each day of the germination period (Equation 2) and mean germination time (MGT) which represents the mean time a seed requires lot to initiate and end germination (Equation 3).

Equation 1: Germination percentage “G%” = $(\sum_{I=1}^K)$

Equation 2: GRI (%) = $[\sum \text{No. of Germinated Seeds} / \text{No. of Days}]$.

Equation 3: MGT (days) = $[\sum n.D / \sum n]$.

Where n: number of seeds newly germinated at time D; D: days from the beginning of the germination test and $\sum n$: final germination.

Morphological characterization of seedlings at early stage of growth development

Destructive harvest of seedlings (Gibreel *et al.*, 2029 and Osman *et al.*, 2026), used to evaluate morphological characteristics of seedlings at early stage after seeds germination and manifestation of cotyledons up to 4 months. 400 healthy and well-developed seedlings of one month old were randomly selected for each species (Ks and Kg) from the germination experiment and kept separately in nursery plots with irrigation regimes of 2 days interval. Morphological characterization of seedlings and growth development of Ks and Kg was assessed in four destructive harvests (100 seedlings each harvest), after 1st, 2nd, 3rd and 4th month after seeds germination. The pattern of seedling morphological development in early growth was described (Das *et al.*, 2001; Malik *et al.*, 2014; Gibreel *et al.*, 2019 and Osman *et al.*, 2026). The seedlings treated as “phanerocotylar” when cotyledons emerge from the test and as “cryptocotylar” when they have not; cotyledon manifestation either food-storage (fleshy) or photosynthetic (paracotyledons); the term “epigeal” was applied for the cotyledons (Seed-leaves) when they raised above the soil surface and considered as “hypogeal” when they remain under the soil (Osman *et al.*, 2026). Morphological measurements of seedlings were made in “cm” using digital Vernier caliper (Model: GT-DC-01, Globaltronics GmbH and Co. KG) and ruler. These included root length and diameter; root collar diameter; shoot length and diameter; hypocotyl and epicotyl length and diameter; compound leaf (mono-pinnate) length, width and petiole length; length and width of pinnae and leaflet. Other count was mad to the number of compound leaves (mono-pinnate) per seedling, number of pinnae pairs per leaf and number of leaflets pairs per pinnae (Gibreel *et al.*, 2019; Osman *et al.*, 2026). The qualitative evaluation of seedlings included shape, color, surface texture and phyllotaxy of cotyledons, leaves and leaflets; stem (hypocotyl and eipcotyl) bark color and texture. Digital photographs were taken at different stages of seedlings development using digital camera (SAMSUNG 18x, WB200F) to complete seedling description.

2.4. Data arrangement and analysis

The data (pods and seeds morphology, seed germination and seedling morphology) was arranged in Excel sheets and the means were subjected to analysis of variance (one-way, two-way ANOVA) by using GLM procedure (Generalized Linear Model: GLM) calculated using SAS Version 9.0 (Statistical Analysis System) (2002) software. The mean separations were carried out using Duncan’s multiple range tests and significance was determined at $p < 0.05$.



Figure 1: The location of Abu Geili riverine forest reserve, Sennar State, Sudan.

The data were analyzed using ANOVA (GLM, SAS v9.0). Significant differences ($p = 0.0001$) between species were observed in morphology at maturity Ks had the highest measures for leaflets number per leaf, while Kg had the largest leaves' dimensions, as well as fruits' and seeds' dimensions. For both Ks and Kg, pre-sowing treatments significantly improved germination during different seasons (autumn, winter and summer) compared with controls. The highest germination success obtained during autumn season (July-October) from hot water treatment (80 °C for 10 min) 94% for Ks and 92% for Kg; followed by cold water (37 °C) treatment overnight 92% for Ks and 90% for Kg. Less success across all pre-sowing treatments was recorded for both species during winter season (December-February). Varying seedlings growth performance in roots' and shoots' morphological characteristics was reported between Ks and Kg. These savannah species Ks and Kg are native to Africa, this study highlighted its possibility to germinate by seeds in wide range of pre-treatment (tap water, hot water and cold water and H_2SO_4), and in different growing seasons (autumn, summer). In addition, the better growing performance and development from early seedling stage up to maturity indicates their adaptive potential to grow in different area and changing climates. These results are decision support tools for the regeneration of multipurpose, exotic forest species such as Ks and Kg that have high agroforestry potential, socio-economic importance and suitable for ecosystem restoration.

RESULTS

The studied species of *Khaya* (*K. senegalensis* and *K. grandifoliola*) revealed based on the of analysis of variance significant variation ($p < 0.0001$) in mature vegetative morphology (Table 1, Figure 1), characteristics of fruits (Table 2), characteristics of seeds (Table 3), seeds germination as affected by pre-treatments and growing seasons (Table 4 and 5) and the morphological growth development of seedlings (Tables 6). Significant differences ($p = 0.0001$) between species were observed in morphology at maturity, where *K. senegalensis* (Ks) recorded the highest measures for tree height (m), diameter at breast height "dbh" (cm), leaflets number per leaf, while *K. grandifoliola* (Kg) had the largest leaves' dimensions (Table 1), as well as fruits' (Table 2) and seeds' (Table 3) dimensions. The average dbh 54.27 ± 9.80 cm and 50.09 ± 6.31 cm and average height 13.83 ± 1.86 and 13.85 ± 2.19 were recorded for Ks and Kg, respectively (Table 1). The leaves of both species are compound paripinnate arranged at the tips of the branches and form dense foliage (Figure 1). However, *Khaya grandifoliola* characterized by large compound paripinnate leaves measuring in average 32.12 ± 3.50 cm length, 23.34 ± 1.52 cm blade length, 26.86 ± 2.72 cm blade width, 9.63 ± 0.85 cm petiole length, 14.81 ± 1.53 cm leaflet length and less number of leaflets in average of 3.20 ± 0.41 pairs per compound leaf. In contrary, the compound paripinnate leaves in *Khaya senegalensis* are relatively small in dimensions, and measuring in average 253.44 ± 2.72 cm length, 20.44 ± 1.75 cm blade length, 15.44 ± 2.72 cm blade width, 5.75 ± 0.74 cm petiole length, 5.45 ± 0.78 cm leaflet length and high number of leaflets in average of 5.27 ± 0.80 pairs per compound leaf (Table 1, Figure 2). The fruits production (Kg/tree/year) was very high for *K. grandifoliola* 35718.45 ± 0.96 and *K. senegalensis* 26573.54 ± 0.30 , with average number of capsules per Kilogram 28.56 ± 0.21 and 43.22 ± 0.01 and average 100-capsules weight (g) 3502 ± 1.67 and 2314 ± 1.27 for the mentioned species, respectively (Table 2). The fruits of both species are almost spherical woody capsule with four segments in *K. grandifoliola* and five segments in *K. senegalensis* with numerous flattened seeds in average per capsule of 13.23 ± 2.09 for *K. senegalensis* and 15.56 ± 0.72 for *K. grandifoliola*, almost rectangular seeds, each with a narrow papery wing and recalcitrant "loses viability when dry" (Table 3). The fruits dehiscent usually open as they fall during fruiting time from January – June as

observed in the study area. With regard to the pre-sowing treatments (H_2SO_4 , Boiling water, Cold water and Control) effect was highly significant ($p < 0.0001$) on the germination percentage, germination rate index and the mean time of germination (Tables 4 and 5) within and among the studied species (Ks and Kg). For both Ks and Kg, pre-sowing treatments significantly ($p < 0.0001$) improved germination during different seasons (autumn, winter and summer) compared with controls (Table 4 and 5). The highest germination success obtained during autumn season (July-October) from hot water treatment (80 °C for 10 min) 94% for Ks and 92% for Kg; followed by cold water (37 °C) treatment overnight 92% for Ks and 90% for Kg. Less success across all pre-sowing treatments was recorded for both species during winter season (December-February). Varying seedlings growth performance in roots' and shoots' morphological characteristics was reported between Ks and Kg. The seeds germination and early growth development of *Khaya senegalensis* (Ks) and *Khaya grandifoliola* (Kg) seedlings at 1st month after germination (30 days), indicated that, seedling of both species are hypogeal, phanerocotylar type with reserve type cotyledon (Figure 2). The hypogeous of seedlings with appears for *Khaya senegalensis* and *Khaya grandifoliola* with long epicotyl on average 7.32 ± 0.04 cm for Ks and 5.56 ± 0.03 cm for Kg after one month (4 weeks) after germination, reaching 19.67 ± 0.04 cm and 15.78 ± 0.03 cm for Ks and Kg respectively after 4 months (16 weeks). The average root-collar 1.64 ± 0.03 cm and 1.49 ± 0.02 cm recorded for Ks and Kg seedlings at 4 month old. The seedlings of Ks and Kg after seeds germinations up to three months (12 weeks) of early growth development of seedlings starts showing simple leaves with long petioles, alternate spiral phyllotaxy and varying blade dimensions (length and width), and gradually developed until 16 weeks (4 months) to imperipinnate compound leaves which, over time, develop into paripinnate compound leaves.

DISCUSSION

The successful establishment and management of indigenous and exotic tree species for Afforestation and/or reforestation programs “forest plantation” is hinged on the germination pattern and early growth of the tree species (Florence, 2004; Nyland, 2016). Although, it is popularly believed that the exotic species perform better than most indigenous species even though there is limited scientific research to verify to this aspects (Onefeli and Akinade, 2023). Elrod and Stansfield, (2003) stated that, the natural variation that occurs among organisms is generally controlled by genetic make-up and/or environmental influence. In fact, the phenotype of members of the same species may vary continuously while their genotype is relatively stable throughout the life of the organisms (Elmund *et al.*, 2004). According to Akinyele and Temitokan (2005), the variation in genetic make-up among organisms is of more taxonomic reliability than environmentally induced one. More and above, the evolutionary changes in the longer term, occur due to environment that may affect the genetic constitution of a population by the pressure of selection it exercises on the population (Akinyele and Osekita, 2011). Therefore, this study focused on the most popular urban exotic species *Khaya senegalensis* (Ks) and *Khaya grandifoliola* (Kg), with special references to their variation in the morphological characteristics at mature stage, fruits “capsules” and seeds characteristics, and also the effect pre-treatments and growing seasons (summer, winter and autumn) on seeds germination characteristics and early growth development of seedling. The variation among the studied species was significant ($p=0.001$), in quantitative measures of tree's morphology (height, dhh), quantitative morphological characteristics of fruits and seeds, as well as considerable variation on qualitative characteristics was reported for the two species. The average tree height (m) and dhh (cm) was vary and the highest in *K. senegalensis* than in *K. grandifoliola*, while both species showed similarly compound paripinnate that were arranged at the tips of the branches and form dense foliage. The average dimensions in “cm” of the compound paripinnate leaves (leaf length, blade length, blade width, petiole length, leaflet length) was high in *K. grandifoliola* than *K. senegalensis*, with low average number of leaflets (pairs) per compound leaves. According to Adjai *et al.*, (2020), *K. senegalensis* (Meliaceae) described as a tree that can grow up to 35 m high with a very thick, scaly bark that ranges in colour from brownish to dark grey. Its trunk is very thick with a generally short and stocky appearance, up to 2 m in diameter, sometimes with a small serif at the base. Its leaves are arranged at the tips of the branches and form dense foliage (Nikiema and Pasternak, 2008). The species *Khaya grandifoliola* C.DC., known as African mahogany, has good size and large increment of wood (Neto *et al.*, 2026). The results of the study revealed high fruits production (Kg/tree/year) that vary between *K. grandifoliola* 35718.45 ± 0.96 and *K. senegalensis* 26573.54 ± 0.30 , with average number of capsules per Kilogram 28.56 ± 0.21 and 43.22 ± 0.01 and average 100-capsules weight (g) 3502 ± 1.67 and 2314 ± 1.27 for the mentioned species, respectively. The fruits are capsules characterized by spherical woody structure, with four to five segment. The seeds per capsules were numerous, flattened, almost rectangular with a narrow papery wing and recalcitrant “loses viability when dry” with average number per capsule of 13.23 ± 2.09 for *K. senegalensis* and 15.56 ± 0.72 for *K. grandifoliola*, The number of seeds per Kilogram was in average 8228 ± 108.01 for *K. senegalensis* greater than *K. grandifoliola* 3837 ± 499.21 . According to Vogt, (1995), *K.*

senegalensis normally produces 6000-7000 seed/kg, but occasionally as few as 3000. Furthermore, Opuni-Frimpong, (2006) reported that, the 1000-seed weight of *Khaya grandifoliola* is 200–300 g.

The regeneration and the successful integration in tree nurseries, as well as for the direct plantation in arid and semi-arid lands, requires the understanding of the aspects of seeds treatments (Kheloufi *et al.*, 2017). Seed problems related to seed dormancy often limit the use of particular species in nurseries for the production of seedlings; it is because seed dormancy can vary from species to species, stage of maturity of seed and degree of drought and consequently pretreatments should be adjusted accordingly (Azad *et al.*, 2012). In this study, the seeds of *K. senegalensis* and *K. grandifoliola* showed significant effects on its germination characteristics as affected by pre-treatments and sowing seasons. However, the highest germination success obtained during autumn season (July-October) from hot water treatment (80 °C for 10 min) 94% for Ks and 92% for Kg, followed by cold water (37 °C) treatment overnight 92% for Ks and 90% for Kg. Less success across all pre-sowing treatments was recorded for both species during winter season (December-February). These findings agreed with Neto *et al.*, (2026) who reported that, *K. grandifoliola* seedlings exhibited better development under the microclimatic conditions of lower temperature 25 °C associated with high relative humidity 86%. Also, it clear from this study that, the seeds of both species which treated by sulphuric acid had low germination percentage through the different growing seasons. However, *Khaya* species seed have thinner seed coats which facilitates faster water uptake and oxygen exchange compared to other forestry species (Onefeli and Akinade, 2023). Among all the tree species, *Khaya senegalensis* and *Khaya grandifoliola* were the first to commence germination at approximately 8 days after planting and had 100% germination at 21st day of planting (Onefeli and Akinade, 2023). The fast germination rate of the mahoganies might be attributed to their seed coat permeability. The structure and thickness of seed coats dictates the rate of water absorption and gas exchange. This findings corroborate the findings done by Egbewole *et al.*, (2018), who stated that *Khaya senegalensis* and *Khaya grandifoliola* has a fast germination rate. Opuni-Frimpong, (2006) stated that, *Khaya grandifoliola* is propagated by seed, it is not necessary to treat seeds before sowing; they can best be sown in seedbeds in the nursery or in pots. However, its fresh healthy seeds have a high germination rate, about 90%, but this decreases rapidly to nearly zero after 2 months under natural circumstances and germination takes 10–35 days and still 76% after 4 months. Furthermore, the study indicated that, germination of *Khaya senegalensis* and *Khaya grandifoliola* is hypogeous with a long epicotyl on average 7.32 ± 0.04 cm for Ks and 5.56 ± 0.03 cm for Kg after one month (4 weeks) after germination, reaching 19.67 ± 0.04 cm and 15.78 ± 0.03 cm for Ks and Kg respectively after 4 months (16 weeks). The average root-collar 1.64 ± 0.03 cm and 1.49 ± 0.02 cm recorded for Ks and Kg seedlings at 4 month old. More and above, it is important before attempting to grow a plant, to know the seed germination type because that helps determine the best seed treatments and sowing options for that seed (Osman *et al.*, 2026). Thus, the study indicated that, early growth development of Ks and Kg seedlings after seeds germinations up to three months (12 weeks) starts showing simple leaves with long petioles, alternate spiral phyllotaxy and varying blade dimensions (length and width), and gradually developed until 16 weeks (4 months) to imperipinnate compound leaves which, over time, develop into paripinnate compound leaves. Similarly Adji *et al.*, (2020), stated that germination of *Khaya senegalensis* is hypogeous with a long epicotyl reaching on average 6.33 cm long and 1.2 mm in average diameter at the collar (approximately 15 days after semi and five (5) days after the appearance of the coleoptile and radicle). The preleaves are almost blunt (absent or stunted petiole), opposite each other and generally identical in length and width. The coleoptile and radicle appear on average 10 days after semi. It is after the pre-leaves that phyllotaxis becomes alternate spiral. The seedling gradually develops simple leaves with longer and longer petioles until, at 11 weeks, the appearance of imperipinnate compound leaves, which, over time, develop into paripinnate compound leaves. It is clear from the findings; significant effects were found between applied pre-treatments and throughout different seasons. However, hot water treatment (100 °C for 1 min) is recommended in this study for enhancing germination of *Khaya* species during summer, winter and autumn. Furthermore, the high germination rate obtained in hot water, cold water and control during autumn is due to favorable environmental conditions, like adequate moisture supply, appropriate gaseous balance and optimum light. Jayashree *et al.*, (2020) stated that, pre-sowing treatments of seed are required for better germination and getting sake of production of seedlings in mass.

CONCLUSION AND RECOMMENDATIONS

Forests, across all continents, provide essential services and products that support economic, environmental, and social development. Afforestation and reforestation programs in natural forests of the Sudan depend largely on native species, while many exotic species showed adaptation, survival ability and success in these programs. Sustainable management of exotic species in Sudan depend on availability of scientific data about their biology, silviculture, ecological conservation and utilization. Therefore, this study focused on *Khaya senegalensis* and *Khaya grandifoliola* as multipurpose exotic species widely used in urban

forestry programs. The variation between the studied species was significant in all studied characteristics (vegetative and reproductive traits) at maturity, seeds germination characteristics and morphological characteristics of seedlings at early stage of growth and development. The study reported high fruits and seeds production for the species. The seeds were recalcitrant, can grow directly when sown fresh and germination percentage may increase with application of suitable pre-treatment. This study indicated that, application of water pre-sowing treatment (hot water, cold water) significantly enhanced the seeds germination during autumn and summer seasons. The careful application of boiled water (100°C) supported with soaking in normal water (37°C) can be used, while the use of concentrated sulphuric acid to pre-treat the seeds is not applicable and causing seed damage. This clarify that, the application of pre-sowing treatments for *Khaya* seeds depends on the nature and structure of the outer layer of seed coat. Based on the results presented, it is clear that the seeds of both species can grow without applying treatment, but pre-sowing treatment is need in somehow to enhance and speed germination. Thus, use of boiling water is highly recommended as low-cost and applicable pre-treatment for better germination success for *K. senegalensis* and *K. grandifoliola* seeds at nursery stage. The morphology of seedling at early growth (one month old) was vary among the species. The seedlings of both were hypogeal “Cotyledons not appear above the soil”, epicotyls in early stage of seeds germination is too long in *K. senegalensis* than *K. grandifoliola*, started with simple leaves that developed late to compound paripinnate leaves. Further studies to evaluate the influence of varying microclimatic conditions in different agro-ecological zones of Sudan on the initial growth and physiological responses of *K. senegalensis* and *K. grandifoliola* are recommended.

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Table 1: Results of Duncan's Multiple Range Test (DMRT) for variation in tree volume (dbh and height) and vegetative parts (branches, leaves) of *Khaya senegalensis* (Ks) and *Khaya grandifoliola* (Kg), trees growing in Abu Geili Riverine forest, Sennar state, Sudan.

Parameters	Species	
	<i>Khaya senegalensis</i> (Ks)	<i>Khaya grandifoliola</i> (Kg)
Diameter at breast height "dbh" (cm)	54.27 ^a (±9.80)	50.09 ^b (±6.31)
Tree height (m)	13.83 ^a (±1.86)	13.85 ^a (±2.19)
Tree volume (m ³)	3.36 ^a (±1.46)	2.74 ^b (±0.65)
Number of compound paripinnate leaves/20 cm branch	11.08 ^a (±1.26)	7.93 ^b (±1.03)
Compound paripinnate leaf length (cm)	25.44 ^b (±2.72)	32.12 ^a (±3.50)
Compound paripinnate leaf blade length (cm)	20.44 ^b (±1.75)	23.34 ^a (±1.52)
Compound paripinnate leaf blade Width (cm)	15.44 ^b (±2.72)	26.86 ^a (±2.72)
Compound paripinnate leaf's petiole length (cm)	5.75 ^b (±0.74)	9.63 ^a (±0.85)
Number of leaflets per leaf (pairs)	5.27 ^a (±0.80)	3.20 ^b (±0.41)
Leaflet length (cm)	7.45 ^b (±0.78)	14.81 ^a (±1.53)
Leaflet width (cm)	3.91 ^a (±0.67)	8.17 ^a (±0.81)
Leaflet surface texture	Smooth, glossy	Smooth, glossy
Leaflet shape	Oblong-elliptic	Oval-elliptic
Leaflet colour	Green-Greenish	Dark-green

Leaflet apex shape	Acuminate	Acuminate
Main stem's Bark texture	Scaly, Rough	Scaly, Rough
Main stem's Bark colour	Brown-brownish to dark grey	Pale brown- Pale
Bole base	Cylindrical-buttressed	Cylindrical-slightly buttressed

❖ Means sharing the same letter in the same row do not differ significantly at ($p = 0.05$) according to Duncan's Multiple Range Test; Means $\pm$ Standard deviation.

Table 2: Results of Duncan's Multiple Range Test (DMRT) for fruits “capsules” and seeds morphological variation of *Khaya senegalensis* (Ks) and *Khaya grandifoliola* (Kg) trees growing in Abu Geili Riverine forest, Sennar state, Sudan.

Parameters	Species	
	<i>Khaya senegalensis</i> (Ks)	<i>Khaya grandifoliola</i> (Kg)
Number of capsules per tree crown/Year	1200.25 ^a (± 4.01)	1020.23 ^b (± 0.66)
Capsules production (Kg/tree/year)	26573.54 ^b (± 0.30)	35718.45 ^a (± 0.96)
Number of Capsules per Kilogram	43.22 ^a (± 0.01)	28.56 ^b (± 0.21)
100-capsules weight (g)	2314 ^b (± 1.27)	3502 ^a (± 1.67)
Capsule length (cm)	7.69 ^a (± 1.12)	7.55 ^b (± 0.78)
Capsule width (cm)	6.93 ^a (± 0.25)	6.55 ^b (± 0.14)
Capsule girth (cm)	6.96 ^a (± 0.57)	6.50 ^b (± 0.32)
Capsule thickness (cm)	6.96 ^a (± 0.57)	6.59 ^b (± 0.06)
Capsule surface texture	Smooth woody	Smooth, glossy
Capsule shape	5-valved, Globose (spherical) woody	4-valved, Ovate-elliptic
Dehiscence	They open from the top into 4-5 valves	They open from the top into 4-5 valves
Ripe capsule colour	Grey-brownish	Greyish brown to Dark brown
Time of fruits ripening	January – June	January - June

❖ Means sharing the same letter in the same row do not differ significantly at ($p = 0.05$) according to Duncan's Multiple Range Test; Means $\pm$ Standard deviation.

Table 3: Results of Duncan's Multiple Range Test (DMRT) for variation in morphological characteristics of seeds of *Khaya senegalensis* (Ks) and *Khaya grandifoliola* (Kg) trees growing in Abu Geili Riverine forest, Sennar state, Sudan.

Parameters	Species	
	<i>Khaya senegalensis</i> (Ks)	<i>Khaya grandifoliola</i> (Kg)
Number of seeds per capsule	13.23 ^b (± 2.09)	15.56 ^a (± 0.72)

Number of seeds per tree crown/Year	314345.35 ^b (± 64315.07)	1124958.11 ^a (± 86577.18)
Seeds production (Kg/tree/year)	434.11 ^a (± 138.77)	36.21 ^b (± 2.70)
Number of seeds per Kilogram	8228 ^b (± 108.01)	3837 ^a (± 499.21)
100-seeds weight (g)	12.15 ^b (± 11.01)	26.06 ^a (± 0.01)
Seed length (cm)	2.52 ^a (± 0.06)	4.53 ^b (± 0.03)
Seed width (cm)	3.51 ^a (± 0.03)	4.44 ^b (± 0.02)
Seed thickness (cm)	0.98 ^a (± 0.01)	0.89 ^b (± 0.06)
Ripe seed color	Brown	Dark brown
Seed surface texture	Smooth, glossy	Smooth, glossy
Seed shape	Winged flattened, Ovate-elliptic slightly narrow papery wings, Ovate-elliptic	Flat, rectangular with narrow papery wings, Ovate-elliptic
Seed type	recalcitrant	recalcitrant

Means sharing the same letter in the same row do not differ significantly at ($p = 0.05$) according to Duncan's Multiple Range Test; Means $\pm$ Standard deviation.

Table 4: Results of analysis of variance (ANOVA) for the variation in seeds germination characteristics (Germination percentage, GRI and MGT) as affected by different pre-sowing treatments within and among *Khaya senegalensis* (Ks) and *Khaya grandifoliola* (Kg), during days 7th, 14th, 21st, and 28th after seeds sowing.

Pre-sowing Treatments	Sowing Seasons	Species	Germination Parameters			Average time of 50% Germination
			Germination n (%)	Germination rate index "GRI" (seed/day)	Mean germination time "MGT" (days)	
Control	Summer (April-May)	Ks	66 ^a (± 8.94)	0.09 ^a (± 0.01)	46.2 ^a (± 6.26)	35.46 ^b (± 9.13)
		Kg	52 ^b (± 8.37)	0.07 ^b (± 0.01)	36.4 ^b (± 5.86)	41.95 ^a (± 8.67)
	Autumn (July-October)	Ks	76 ^a (± 5.48)	0.11 ^a (± 0.01)	53.2 ^a (± 3.83)	31.90 ^a (± 4.35)
		Kg	66 ^b (± 11.40)	0.09 ^b (± 0.02)	46.20 ^b (± 7.98)	30.97 ^b (± 6.36)
	Winter (December-February)	Ks	36 ^a (± 11.40)	0.05 ^a (± 0.02)	36.77 ^a (± 7.81)	24.17 ^b (± 3.78)
		Kg	28 ^b (± 8.37)	0.04 ^b (± 0.01)	19.60 ^b (± 5.86)	38.62 ^a (± 10.41)

Cold water (37 °C)	Summer (April-May)	Ks	88 (±8.37)	0.13 (±0.01)	61.6 (±5.86)	27.30 (±5.37)
		Kg	78 (±8.37)	0.11 (±0.01)	54.60 (±5.85)	31.61 (±2.93)
	Autumn (July-October)	Ks	92 (±8.37)	0.13 (±0.01)	64.40 (±5.86)	23.59 (±5.04)
		Kg	90 (±7.07)	0.13 (±0.01)	63 (±4.65)	31.59 (±6.25)
	Winter (December-February)	Ks	64 (±11.40)	0.09 (±0.02)	44.80 (±7.98)	22.17 (±6.12)
		Kg	60 (±7.07)	0.09 (±0.01)	42 (±4.95)	29.20 (±4.25)
Hot water (100 °C)	Summer (April-May)	Ks	90 (±7.07)	0.13 (±0.01)	63 (±4.95)	33.55 (±3.73)
		Kg	80 (±10.00)	0.11 (±0.01)	56 (±7.00)	36.15 (±5.78)
	Autumn (July-October)	Ks	94 (±5.48)	0.13 (±0.01)	65.80 (±3.83)	35.19 (±7.64)
		Kg	92 (±12.25)	0.13 (±0.02)	63 (±8.57)	43.49 (±3.73)
	Winter (December-February)	Ks	78 (±8.37)	0.11 (±0.01)	54.60 (±5.86)	27.84 (±6.54)
		Kg	66 (±11.40)	0.09 (±0.02)	46.20 (±7.98)	31.77 (±4.14)
H ₂ SO ₄ (98% for 5 minutes)	Summer (April-May)	Ks	42 (±11.40)	0.07 (±0.02)	32.2 (±7.98)	37.78 (±7.00)
		Kg	40 (±7.07)	0.06 (±0.01)	28 (±4.95)	45.36 (±5.76)
	Autumn (July-October)	Ks	44 (±8.94)	0.06 (±0.01)	30.80 (±6.26)	40.18 (±6.71)
		Kg	38 (±13.04)	0.05 (±0.02)	26.6 (±9.13)	49.65 (±11.61)
	Winter (December-February)	Ks	30 (±7.07)	0.04 (±0.01)	21 (±4.95)	43.63 (±5.45)
		Kg	22 (±13.04)	0.03 (±0.01)	15.40 (±9.13)	47.95 (±8.71)

❖ Where: GRI: Germination Rate Index; MGT: Mean Germination Time (days). Means sharing the same letter in the same row do not differ significantly at ($p = 0.05$) according to Duncan's Multiple Range Test; Means ± Standard deviation.

Table 5: Results of analysis of variance (ANOVA) for the variation in seeds germination characteristics (Germination percentage, GRI and MGT) as affected by different pre-sowing treatments within and among *Khaya senegalensis* (Ks) and *Khaya*

grandifoliola (Kg), during days 7th, 14th, 21st, and 28th after seeds sowing.

Planting season	Pretreatments	<i>Khaya senegalensis</i> (Ks)				<i>Khaya grandifoliola</i> (Kg)			
		Germination (%)	GRI (seed/day)	MG T (days)	Average time of 50% germination	Germination (%)	GRI (seed/day)	MG T (days)	Average time of 50% germination
Summer (April-May)	Control	66 ^c (±8.94)	0.09 ^a (5/32.±0.01)	46.2 ^a (±6.26)	35.46 ^b (±9.13)	52 ^b (±8.37)*	0.07 ^b (±0.01)	36.4 ^b (±5.86)	41.95 ^a (±8.67)
	Tap Water	88 ^b (±8.37)	0.13 ^a (±0.01)	61.6 (±5.86)	27.30 (±5.37)	78 (±8.37)	0.11 (±0.01)	54.60 (±5.85)	31.61 (±2.93)
	Hot Water	90 ^a (±7.07)	0.13 ^a (±0.01)	63 (±4.95)	33.55 (±3.73)	80 (±10.00)	0.11 (±0.01)	56 (±7.00)	36.15 (±5.78)
	H2SO4	46 ^d (±11.40)	0.07 (±0.02)	32.2 (±7.98)	37.78 (±7.00)	40 (±7.07)	0.06 (±0.01)	28 (±4.95)	45.36 (±5.76)
Autumn (July-October) 0.96	Control	76 ^a (±5.48)	0.11 ^a (±0.01)	53.2 ^a (±3.83)	31.90 ^a (±4.35)	66 ^b (±11.40)	0.09 ^b (±0.02)	46.20 ^b (±7.98)	30.97 ^b (±6.36)
	Tap Water	92 (±8.37)	0.13 (±0.01)	64.40 (±5.86)	23.59 (±5.04)	90 (±7.07)	0.13 (±0.01)	63 (±4.65)	31.59 (±6.25)
	Hot Water	94 (±5.48)	0.13 (±0.01)	65.80 (±3.83)	35.19 (±7.64)	90 (±12.25)	0.13 (±0.02)	63 (±8.57)	43.49 (±3.73)
	H2SO4	44 (±8.94)	0.06 (±0.01)	30.80 (±6.26)	40.18 (±6.71)	38 (±13.04)	0.05 (±0.02)	26.6 (±9.13)	49.65 (±11.61)
Winter (December-February) 1.41	Control	36 ^c (±11.40)	0.05 ^a (±0.02)	36.77 ^a (±7.81)	24.17 ^b (±3.78)	28 ^b (±8.37)	0.04 ^b (±0.01)	19.60 ^b (±5.86)	38.62 ^a (±10.41)
	Tap Water	64 ^b (±11.40)	0.09 (±0.02)	44.80 (±7.98)	22.17 (±6.12)	60 (±7.07)	0.09 (±0.01)	42 (±4.9)	29.20 (±4.25)

								5)	
	Hot Water	78 ^a (±8.37)	0.11 (±0.01)	54.60 (±5.86)	27.84 (±6.54)	66 (±11.40)	0.09 (±0.02)	46.20 (±7.98)	31.77 (±4.14)
	H2SO4	30 ^c (±7.07)	0.04 (±0.01)	21 (±4.95)	43.63 (±5.45)	22 (±13.04)	0.03 (±0.01)	15.40 (±9.13)	47.95 (±8.71)

❖ Where: GRI: Germination Rate Index; MGT: Mean Germination Time (days). Means sharing the same letter in the same row do not differ significantly at ($p = 0.05$) according to Duncan's Multiple Range Test; Means ± Standard deviation.

Table 6: Variation in monthly growth development of seedlings parameters (shoots and roots) between *Khaya senegalensis* (Ks) and *Khaya grandifoliola* (Kg) during month 1 (M1), month 2 (M2), month 3 (M3) and month 4 (M4) after seeds germination and cotyledons manifestation.

Seedling parameters	Species and monthly measurement of seedlings parameters							
	Month 1 (week 4)		Month 2 (Week 8)		Month 3 (Week 12)		Month 4 (Week 16)	
	Ks	Kg	Ks	Kg	Ks	Kg	Ks	Kg
Type of germinate	Hypogeal “Hypogeous”	Hypogeal “Hypogeous”	Hypogeal “Hypogeous”	Hypogeal “Hypogeous”	Hypogeal “Hypogeous”	Hypogeal “Hypogeous”	Hypogeal “Hypogeous”	Hypogeal “Hypogeous”
Root length (cm)	5.16 ^a (±0.86)	4.07 ^b (±1.06)	6.45 ^a (±0.86)	5.43 (±1.06)	8.06 ^a (±0.86)	7.24 ^b (±1.06)	10.08 ^a (±0.86)	7.89 ^b (±1.06)
Root width (cm)	0.49 ^a (±0.04)	0.32 ^b (±0.04)	0.61 ^a (±0.04)	0.42 ^b (±0.04)	0.76 ^a (±0.04)	0.56 ^b (±0.04)	0.85 ^a (±0.04)	0.76 ^b (±0.04)
Root collar width (cm)	1.22 ^a (±0.03)	1.02 ^b (±0.02)	1.49 ^a (±0.03)	1.23 ^a (±0.02)	1.54 ^a (±0.03)	1.39 ^b (±0.02)	1.64 ^a (±0.03)	1.49 ^b (±0.02)
Shoot height/length (cm)	10.32 ^a (±0.04)	8.56 ^b (±0.03)	12.90 ^a (±0.04)	11.41 ^b (±0.03)	16.13 ^a (±0.04)	15.21 ^b (±0.03)	22.17 ^a (±0.04)	18.32 ^b (±0.03)
Epicotyl length (cm)	7.32 ^a (±0.04)	5.56 ^b (±0.03)	9.95 ^a (±0.04)	8.68 ^b (±0.03)	13.55 ^a (±0.04)	12.28 ^b (±0.03)	19.67 ^a (±0.04)	15.78 ^b (±0.03)
Number of simple leaves	4.02 ^a (±0.04)	3.11 ^b (±0.04)	4.02 ^a (±0.04)	3.11 ^b (±0.04)	7.52 ^b (±0.04)	8.44 ^a (±0.04)	Absent	Absent
simple leaves' length (cm)	7.86 ^a (±0.14)	6.84 ^b (±0.24)	9.08 ^a (±0.11)	7.74 ^b (±0.02)	9.28 ^a (±0.11)	7.76 ^b (±0.02)	Absent	Absent
simple leaves' blade length (cm)	5.63 ^b (±0.02)	7.02 ^a (±0.03)	5.69 ^b (±0.04)	7.89 ^a (±0.03)	5.89 ^b (±0.04)	7.91 ^a (±0.03)	Absent	Absent

simple leaves' blade width (cm)	2.22 ^b (±0.03)	3.35 ^a (±0.03)	2.80 ^b (±0.03)	3.85 ^a (±0.01)	3.95 ^a (±0.03)	4.87 ^b (±0.12)	Absent	Absent
Simple leaves' petiole length (cm)	3.38 ^b (±0.04)	4.63 ^a (±0.04)	3.88 ^b (±0.04)	4.69 ^a (±0.04)	3.98 ^b (±0.04)	5.88 ^a (±0.04)	Absent	Absent
Number of paripinnate compound leaves/seed ling (pairs)	Not developed	Not developed	Not developed	Not developed	Not developed	Not developed	12.65 ^a (±0.04)	10.87 ^b (±0.04)
Paripinnate compound leaves' length (cm)	Not developed	Not developed	Not developed	Not developed	Not developed	Not developed	11.60 ^a (±0.12)	10.35 ^b (±0.05)
Paripinnate compound leaves' petiole length (cm)	Not developed	Not developed	Not developed	Not developed	Not developed	Not developed	3.99 ^b (±0.04)	5.91 ^a (±0.04)
Number of leaflets per paripinnate compound leaves/seed ling (pairs)	Not developed	Not developed	Not developed	Not developed	Not developed	Not developed	5.01 ^a (±0.88)	4.33 ^b (±0.92)
Leaflet length (cm)	Not developed	Not developed	Not developed	Not developed	Not developed	Not developed	8.42 ^b (±0.04)	9.55 ^a (±0.13)
Leaflet width (cm)	Not developed	Not developed	Not developed	Not developed	Not developed	Not developed	4.98 ^b (±0.03)	6.89 ^a (±0.12)
Root colour	Pale brown	Pale brown	Pale brown	Pale brown	Pale brown	Pale brown	Pale brown	Pale brown
Leaflets colour	Pale green-greenish	Dark green	Pale green-greenish	Dark green	Pale green-greenish	Dark green	Pale green-greenish	Dark green
Leaflets shape	Oblong	Oblong-elliptic	Oblong	Oblong-elliptic	Oblong	Oblong-elliptic	Oblong	Oblong-elliptic
Leaflet	Obtuse	Obtuse	Obtuse	Obtuse	Obtuse	Obtuse	Obtuse	Obtuse

apex type								
Leaf phayllotaxy	alternate	alternate	alternate	alternate	alternate	alternate	alternate	Alternate
Leaflet's phayllotaxy	Opposite	Opposite	Opposite	Opposite	Opposite	Opposite	Opposite	Opposite

Means sharing the same letter in the same row do not differ significantly at ($p = 0.05$) according to Duncan's Multiple Range Test; Means $\pm$ Standard deviation.

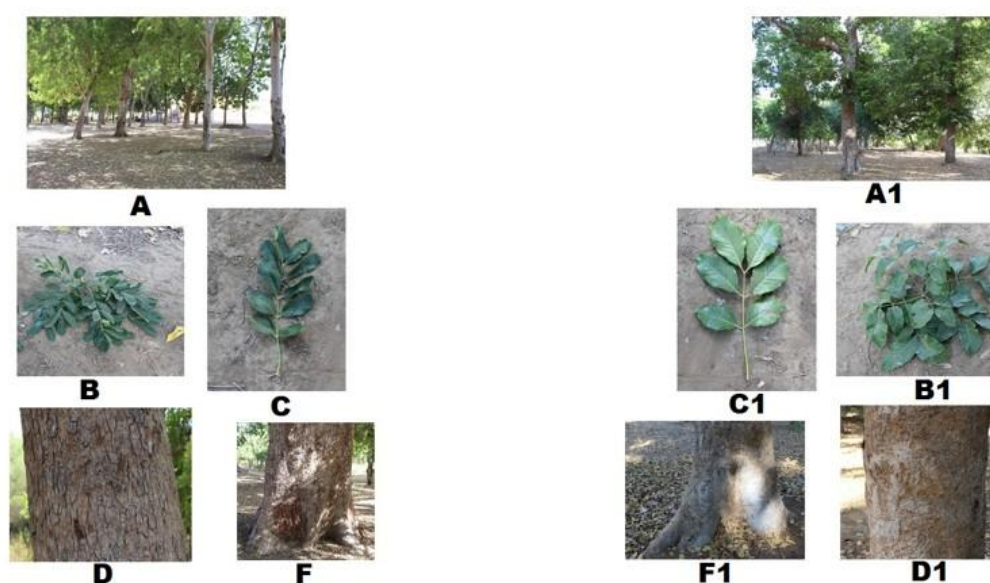


Figure 1: Mature trees *Khaya senegalensis* (A), foliage (B), leaves (C), Bark (D), bole base (F); and *Khaya grandifoliola* trees (A1), leaves (C1), foliage (B1), Bark (D1), bole base (F1) growing at plantation in Abu Geili riverine forest, Sennar state, Sudan (Photographed by author, 2026).

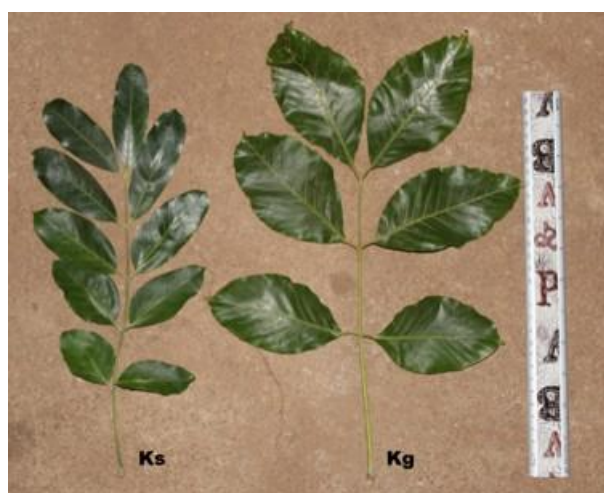


Figure 2: Mature compound paripinnate leaf of *Khaya senegalensis* (Ks) and *Khaya grandifoliola* (Kg) trees, showing variation in leaflets shape and dimensions.

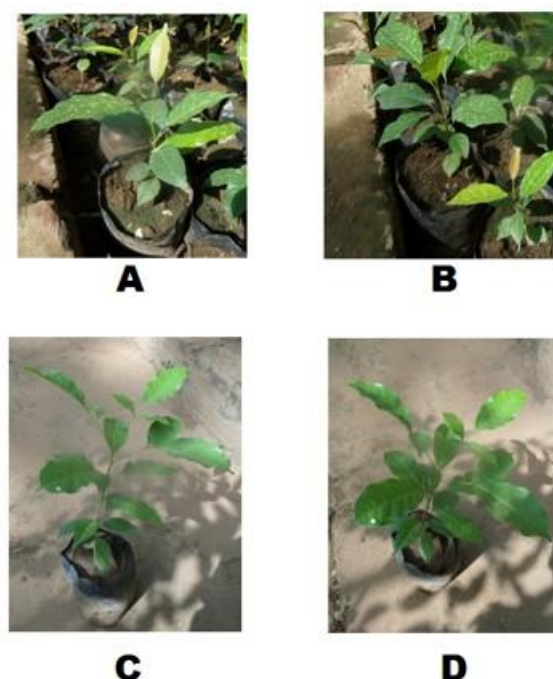


Figure 3: Seedlings growth of *Khaya senegalensis* at one-month-old (A) and three-month-old (C); and *Khaya grandifoliola* at one month old (B) and three month old (D), showing long epicotyl with simple, alternate leaves.

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