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Annual growth and wood characteristics of *Ginkgo biloba* L. in Egypt: A pilot study

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Countries are implementing various strategies, including wood tree planting, to reduce importing costs, Egypt is a major importer of wood. This study aims to investigate the annual growth and wood characteristics of the introduced tree *Ginkgo biloba* L., cultivated in a few sites in Egypt. In one accessible site (Alexandria University Botanical Garden) (ALEX), wood samples and cores were extracted from male and female trees to measure tree-ring widths, basal area increment (BAI), and wood characteristics. Results showed a strong relationship between wood dry weight and the volume of a female tree (R^2=0.9948), with wood density=0.486 g.cm^{-3} at 12% moisture. Female tree sequestered 43.92kg CO_2/year. The trees' age was 24 years. The average annual growth and BAI for female and male trees were 3.96 mm, 5.05 mm, and 109.3%, 47.7%, respectively. *G. biloba* has a tracheid length higher than or close to the known wood species value. The wood lies among the medium-density wood species, with a lighter and less dense microstructure composition, with 45.39% cellulose, 21.59% hemicellulose, and 30.67% lignin. The mean values of modulus elasticity, compressive strength, and hardness were 4834.40 N.mm^{-2}, 29.04 N.mm^{-2}, and 1229.2 N, respectively. These results suggest that *G. biloba* wood may be well-suited for paper making, crafting lightweight furniture, and carpentry purposes. Expanding *G. biloba* cultivation along the Mediterranean coast of Egypt can fill the wood importing gap. Since this is a pilot study, we recommend further research on *G. biloba* cultivation in different soil types in Egypt with a considerable sampling.

Keywords: *Ginkgo biloba; Tree-rings; Wood characteristics; Acclimation; Carbon sequestration, Wood industry*

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INTRODUCTION

In 2022, Egypt's imports of wood, wood products, and wood charcoal were US$1.5 billion, according to the United Nations COMTRADE database on global commerce (Trading Economics, 2024). According to Shaltout and Bedair (2022), there are 52 native tree species in Egypt; 31 taxa are evaluated as threatened with extinction. Many of these taxa are either under *in situ* conservation in the protected areas or under *ex-situ* conservation. Wood is one of the most useful plant commodities in the world today, and it played an ever-greater role in the past. Aside from its use as a structural material, wood is valuable as a source of paper, rayon, various chemicals, and fuel (Abdel Razik, et al., 1996). The woods of these species are mostly not suitable for heavy furniture or carpentry applications. At the national scale, the flora of Egypt as indicated in Boulos (2009) includes 2145 plant species, with trees constituting only 2.7% of the total plant species (Zahran and El-Ameir 2012). While the contribution of woody taxa as trees and shrubs (40 %) in most of the international Botanic Gardens in Egypt (Cultivated flora), which are considered introduced (exotic) taxa (Heneidy 2010; Heneidy et al., 2024a). We urgently need to gain insight into introduced, invasive, and alien species to manage and protect our natural flora (Rashed 2022; Heneidy et al., 2024b Heneidy et al., 2024c). Due to the deficiency of economic woody trees and the import burden of wood from abroad, the afforestation of new economic woody tree species in Egypt using treated wastewater became a national project (MSEA 2004). Many non-native woody tree species were cultivated in desert artificial forests in Egypt using the primary treated wastewater such as *Khaya senegalensis* (Desr.) A. Juss. (dry zone Mahogny), *Dalbergia sissoo* Roxb. (Shisham), *Eucalyptus camaldulensis* Dehnh. (River Redgum), *Eucalyptus citriodora* Hook. *Coryambia citriodora* (Hook.) K.D. Hill and Johnson (Lemon scented gum), and *Casuarina* spp. (Australian pine) (Farahat et al., 2012). Nevertheless, due to the low wood quality of these species compared to the imported wood, there is an urgent need to explore the suitability of more non-native woody species to be cultivated in Egypt. This eventually will help in the local production of wood, economic use of the treated wastewater, cleaning of the air, and carbon sequestration.

Research studies revealed that *Ginkgo biloba* L. is a kind of tree with a high carbon sequestration capacity and is one of the dominant tree species suitable for urban ecosystems (Zhang et al., 2023). *G. biloba*, the rare relic tree (family Ginkgoacea, maidenhair tree), is a dioecious, deciduous tree that reaches 40 m tall with light gray-brown bark, the tree crown is conical and densely branched; branchlets are dimorphic (long and short). Petiolate leaves sparsely and spirally arranged on long branchlets, blade pale green, turning bright yellow in autumn 8-13 × 5-8 cm, leaf blade on long branchlets divided by a deep, apical sinus into two lobes. In contrast, leaf blades on short branchlets have undulate distal and margin notched apex. Reproductive structures are produced in clusters in axils of scalelike leaves at the apex of short branchlets before leaves expand. Ivory-colored catkinlike pollen cones 1.2-2.2 cm long. Seeds elliptic, narrowly obovoid, ovoid, or sub globose, 2.5-3.5 × 1.6-2.2 cm; sarcotesta yellow, or orange-yellow glaucous, with rancid odor when ripe; sclerotesta white, with 2 or 3 longitudinal ridges. Pollination from March to April, and seed maturity from September to October (Cheng & Fu, 1978).

G. biloba is a native tree to Southeast China, introduced to North-Central China, South-Central China, Illinois, Japan, Korea, and Romania (POWO 2024). It has now been redistributed on all continents of the world through artificial introduction (Zu et al., 2021). The global distribution of *G. biloba* is concentrated in the mid-latitudes of the Northern Hemisphere, and there are also small parts in the same latitude zone in the Southern Hemisphere (Wang et al., 2023).

G. biloba is used as a common landscaping and urban greening tree species, and it is considered an important economic tree species in China. Planting of *G. biloba* for its commercial and pharmaceutical products based on leaves was a target for many countries such as China, the United States, Korea, Canada, New Zealand, and France (Singh et al., 2008). Ma et al., (2022) reported that *G. biloba* biomass had many bioactive components with potential uses in food, chemical raw materials, and biomedical industries. It has high free radical scavenging abilities (>92%), is equivalent to vitamin C, and can be used as an antioxidant in food additives. The three main primary groups of bioactive chemicals isolated from *G. biloba* fruits and leaves are flavonoids, terpenoids, and polysaccharides. The bioactive compounds in leaves and fruits of *G. biloba* are used to treat respiratory infectious diseases, such as antioxidants and bacteriostasis, antiasthma, wound healing, and neuroprotective properties. Likewise, they treat hypertension, cardiovascular and cerebrovascular diseases, hypercholesterolemia, and cerebral vasospasm (Sati et al., 2012; Xu et al., 2012; Cao et al., 2018; Fang et al., 2020; Guo et al., 2020a). It is known that plant pests rarely affect *G. biloba* because its leaves have antifeedant activities against *Hyphantria cunea* larvae (Long et al., 2016).

It was found that well-watered and well-drained soils are ideal for *G. biloba* growth (Royer et al., 2003). In many towns and gardens, *G. biloba* is used as a visually pleasing shade tree that is extremely resistant to pollution (Wang et al., 2023). Most gardeners prefer the cultivation of female *G. biloba* trees because it is less allergic compared to the male trees according to the Orgen Plant Allergy Scale (Orgen 2000). There are only 31 trees of *G. biloba* cultivated in five gardens in Cairo and Alexandria, Egypt, for educational and aesthetic purposes (Bidak et al., 2022). Among these gardens is the botanic garden at the Faculty of Science, Alexandria University (Egypt) N: 31° 11' 19.39'' E: 29° 54' 28.18. In this garden, there are only two trees (one female and one male), which were cultivated a long time ago. There is no data about the age of *G. biloba* trees in this garden, their annual growth, or wood characteristics outside its native range.

Therefore, the wider objective of this study was to evaluate the growth of *G. biloba* trees in Egypt and the suitability of its wood for industrial and common applications. One of the challenges in this study is the sampling limitation where there were no permissions to collect wood samples or do any morphometric measurements in most sites in Egypt. We think that this is a clear drawback or limitation of this study that may affect the accuracy of some of the gathered data due to the limited sample size. Accordingly, we only used the two accessible trees in Alexandria. The specific objectives of this study were to 1-estimate the annual growth of *G. biloba* and its possible contribution to carbon sequestration, 2- identify its wood characteristics under the semi-arid environment of Egypt and outside its native range, 3- potential use of *G. biloba* wood as an alternative to some of the planted non-native species in Egypt.

MATERIALS AND METHODS

Tree measurements

The trees' heights and circumferences were measured at each meter above the soil surface to the maximum point of the stem. Then, the volume measurement is established for the female tree by following the stem shape geometry procedures outlined in (Husch et al., 2002). To estimate wood's water content and the relationship between wood dry weight and its volume, a few wood samples (N=13) from the main lateral branches of the female *Ginkgo* tree were collected. Wood samples were oven-dried at 60 ℃ until constant weight. The percentage of water content of the wood samples was calculated as follows:

%water content=(Fresh weight-dry weight/dry weight)*100 (1)

To measure the bulk wood density (gravimetric/ volumetric wood density), a subset of the same wood samples of branches was used for dry weight and volume measurements, and then the bulk volume was determined by water displacement (Hill and Papadopoulos 2001). The bulk wood density was calculated by dividing the sample weight by the sample volume.

The relationship between wood volume ($V = \pi r^2 h$, π = 3.14, r = radius, and h = height) and dry weight was plotted, and the linear regression model equation and its coefficient of determination (R^2) were calculated. According to the created linear regression model between the volume and dry weights of the sampled wood, the dry weight of the main pole was calculated after the calculation of its volume. To calculate the carbon stock in the female tree, the total aboveground dry weight was multiplied by 50% (Xu and Mitchell 2011). The annual C sequestration by *Ginkgo biloba* was calculated by dividing the total C stock per tree's age (24 years). To calculate the weight of carbon dioxide sequestered in a tree, the weight of carbon in the tree was multiplied by 3.6663 (=the ratio of CO_2 to C) (Chavan and Rasal 2011).

Sampling, processing, and measurements

Ginkgo biloba is not a native species to Egypt, and it is cultivated in very few sites as a single male or female tree. To determine the age of the two trees in the Faculty of Science botanic garden of Alexandria University, two core samples were collected at breast height (1.3 m) on opposite sides of each tree. Cores were mounted on wooden support using glue, and then after drying well, they were sanded until the ring borders became visible. The cores were scanned at 600 dpi using a Canon Scanner (model MP2890). The tree-ring widths (TRW) in each core were measured in the scanned images of the cores to the nearest 0.01 mm using CooRecorder 7.4 and the related CDendro 7.4 software (http://www.cybis.se). The series intercorrelation, missing rings, and possible dating errors were checked by using COFECHA 6.06P software (Grissino-Mayer 2001). To remove age-related growth trends from the data (Fritts 2001), the average TRW for female and male Ginkgo trees was determined using R software (R Core Team 2021). Basal area increment (BAI) was calculated for each tree assuming circular stems according to the following equation,

$$BAI= (X_y - X_{y-1})/ X_{y-1} \quad (2)$$

Where X is the basal area in year Y, Xy-1 is the basal area in the previous year. The average annual growth rate of female and male *Ginkgo* was calculated.

Wood characteristics

This part of the study was carried out at the Forestry and Wood Technology Department, Faculty of Agriculture, Alexandria University. The wood samples were prepared from branches (diameter: 10 cm) and were free from any visible defects. The wood properties of *Ginkgo* were compared with some imported softwood species and important locally grown soft- and hardwoods, providing valuable information for potential applications in the wood industry in Egypt.

Anatomical features measurement

In the context of anatomical features examination, transverse, tangential, and radial sections (thickness= 30 µm) were prepared using a sliding microtome. The sections underwent a staining process with 1% safranin. Subsequently, a systematic dehydration process ensued, involving sequential immersions in ethanol alcohol with increasing concentration levels (50%, 60%, 70%, 80%, 90%, and 100%), each lasting five minutes. Following dehydration, the sections were immersed in xylene. Finally, the wood sections were embedded in Canada Balsam and then oven-dried at 60°C for 24 h (Gärtner and Schweingruber, 2013). The anatomical measurements were performed with the aid of a stage micrometer and image analysis. Chips prepared for fiber length measurement were macerated using a mixture of hydrogen peroxide and glacial acetic acid.

Physical properties

The air-dry density at 12% MC was calculated as the ratio of air-dry mass to volume at a moisture content of 12% (ASTM D2395 2002).

$$\rho = \frac{m_{12}}{V_{12}} \quad (3)$$

where ρ is the air-dry density, m_{12} and V_{12} are air-dried mass and volume at 12 % MC, respectively.

Shrinkage measurements in the tangential, radial, and longitudinal directions were determined by assessing the transition from the green state to the oven-dried state, following the guidelines outlined in ISO 13061-13 (2016). The specimens, originally sized at 20 x 20 x

30 mm in their true cut state, underwent shrinkage analysis. Additionally, the tangential-to-radial shrinkage ratio was calculated. The shrinkage percentage was calculated using the following equation:

$$\beta\ (\%) = \frac{d_1 - d_2}{d_1} \times 100 \quad (4)$$

where, β is the shrinkage in the tangential, radial, or longitudinal directions, d_1 is the green dimensions, and d_2 is the oven-dried dimension.

Chemical compositions

The extractive content was obtained by successive extraction in solvents using a Soxhlet extractor (ASTM D1105-96 2013). Ash content was determined at 600 °C in a muffle (ASTM D1102-84 2013). Insoluble lignin was determined (ASTM D1106-96 2013). Cellulose content was determined following Kürschner and Hoffer (1929). The hemicellulose content was determined by subtracting the combined values of all identified chemical components, including ash and total extractives from 100.

Mechanical Properties Testing

The dynamic Young's modulus was tested following (Hassan et al., 2013) and calculated using equation 5,

$$E_L = \rho . V^2 \quad (5)$$

Where E_L is the dynamic Young's modulus, ρ is the density, and *V* is the longitudinal sound velocity.

Side hardness on the tangential direction using the Janka ball tool and maximum crushing strength specimens have been prepared following BS 373 (1957). All the mechanical tests were performed on conditioned samples at 23°C and 65% relative humidity until constant mass before testing. Equation 6 is used to calculate the compressive strength,

$$\sigma = \frac{P_{max}}{A} \quad (6)$$

where σ, is the maximum crushing strength, P_{max} is the maximum load, and A is the cross-sectional area of the test specimen.

RESULTS AND DISCUSSION

Tree measurements

The maximum height of female and male Ginkgo trees was 14 m and 15 m, while DBH was 96.0 cm and 75.5 cm, respectively. The total volume for the female tree was 0.2336 m^3. The average water content of the representative branches' wood samples was 130.3%, with bulk wood density = 0.45 $g.cm^{-3}$. This value for wood density is too close to the wood density for the air-dried wood (0.486 $g.cm^{-3}$) at 12% moisture. Drawing the relationship between wood dry weight and its volume (Figure 1), a linear regression model was developed with a coefficient of determination (R^2) equal to 0.9948. Accordingly, the total dry weight of the female tree, its total carbon stock, and the annual C sequestration were 575.07 kg, 287.53 kg, and 12.0 kg/year, respectively. The total sequestered CO_2 by a single female tree (tree's age = 24 years) was 1054.19 kg CO_2. Consequently, the annual sequestered CO_2 by *G. biloba* female tree was 43.92 kg CO2/year. These results agree with Meng et al., (2023) and Zhang et al., (2023) who reported that *G. biloba* is a good species for carbon sequestration. The amount of CO_2 sequestered by an individual tree can vary greatly depending on several factors, including tree species, size, age, climate, and soil conditions (Toochi 2018). For instance, the annual CO_2 sequestration rates (kg CO_2 per year) of Oak, Maple, Pine, and Birch are 22, 18, 15, and 12 (Nowak and Crane 2002). It is crucial to remember that these are only estimations and that a given tree may trap much less or much more CO_2. For instance, in a warm, humid area, a huge, mature oak tree could absorb hundreds of kilograms of CO_2 annually (Balaganesh et al., 2022).

Tree-ring widths and basal annual increment

Figure 2 shows the annual tree-ring widths (TRW raw data and indices) of *G. biloba* at the studied site. The age of the male and female trees was 24 years (1999-2022). The series intercorrelation and average mean sensitivity between the four tested series were 0.623 and 0.381, respectively. It is revealed from the figure that *G. biloba* grew exponentially at the beginning of its growth during the juvenile age (1999-2012) for 14 years, then the growth became slow with time. The male tree had a higher annual growth rate compared to the female tree except for the 2014 and 2015 years. This was a known growth behavior in many tree species such as *G. biloba* (Wang et al., 2020). The average annual growth for female and male trees was 3.96 mm and 5.05 mm, respectively. After detrending the tree-ring data (Figure 2), the tree-ring indices showed the same growth trends as TRW which reflect the prevailing environmental signal around the trees. The basal area increment (BAI, Figure 3) of *G. biloba* was higher at the juvenile stage than at the mature stage, with more BAI in the male tree than the female tree i.e., decrease with aging. The average BAI was 109.3% and 47.7% for male and female trees, respectively. .

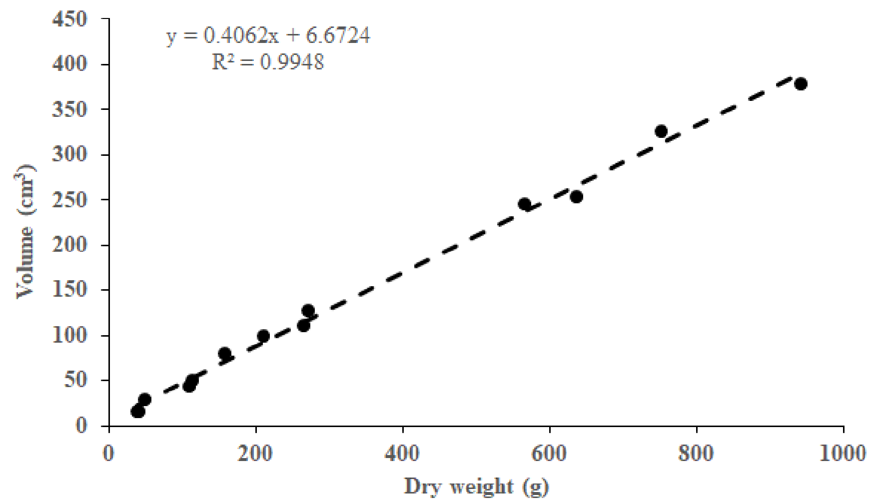

Figure 1. Relationship between the dry weights of branch wood samples and its volume for *G. biloba*. The dashed line is the linear regression line, R^2= coefficient of determination

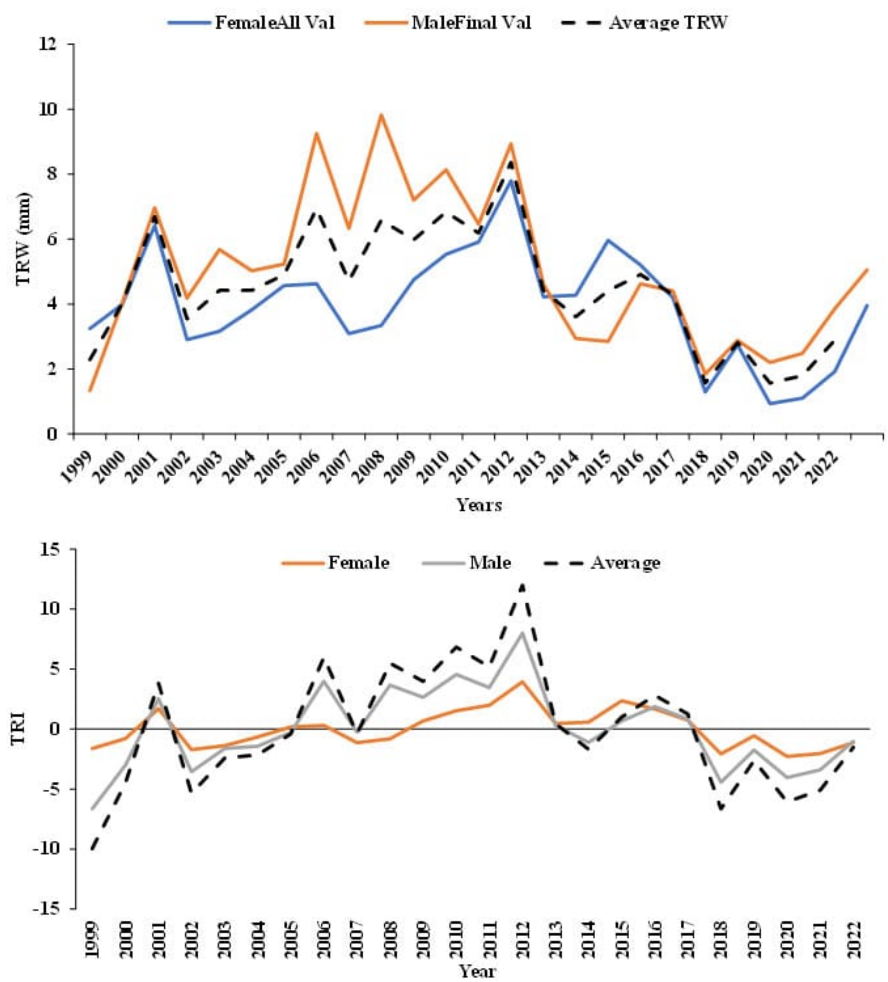

Figure 2. Tree-ring widths (mm) and their indices for the male and female *G. biloba* trees from 1999 to 2022.

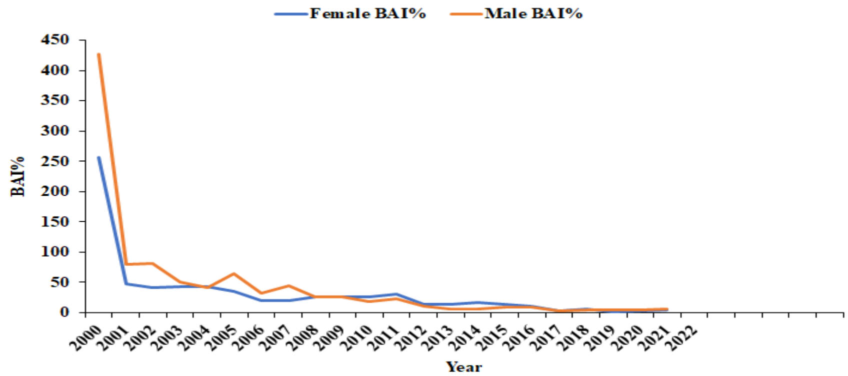

Figure 3. The percentage of basal area increment (BAI%) for the growth of *G. biloba* from 1999 to 2022.

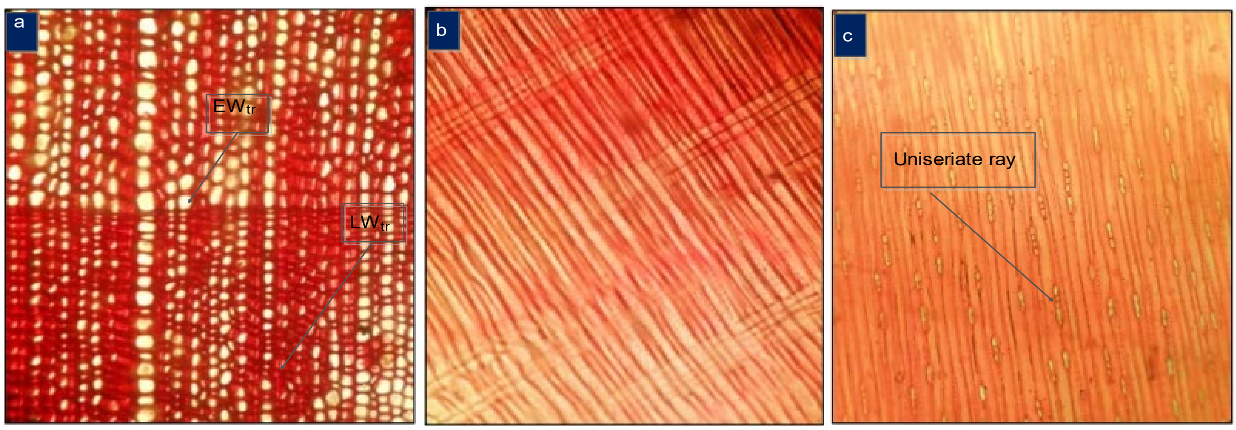

Figure 4. Cross (a), radial (b), and tangential (c) sections of *G. biloba* wood. EW_{tr} and LW_{tr} are earlywood and latewood tracheids, respectively.

Wang et al., (2020) found that the average TRW of a 25-year-old tree *G. biloba* was 5.25 mm, while that of a 991-year-old tree was about 1.20 mm. This means that *G. biloba* trees grow normally during this age compared to their growth in native habitats in China

Wood characteristics
Anatomical features measurement

Figure 4 (a-c) shows transverse, radial, and tangential sections of *G. biloba* wood. By presenting these wood sections, we aim to provide a comprehensive visual representation of *G. biloba* wood anatomy for identification. Microscopically, the distinct growth rings and regularly arranged tracheid are observed. Likewise, the transition between the earlywood and latewood tracheids was gradual and recognized by the structural differences in tracheid wall thickness and its radial diameter as reported for the plant by the IAWA Committee (2004). In this context, Lee and Eom (1987) reported that *G. biloba* exhibited a gradual transition from earlywood to latewood in normal wood stems. The tangential section (Figure 4c) shows uniseriate rays were observed. Scott et al., (1962) reported the presence of almost exclusively uniseriate rays in *G. biloba* like other conifers

Table 1 shows the mean tracheid length, earlywood tracheid diameter, latewood tracheid diameter, and ray length of *G. biloba* wood. The mean tracheid length of *G. biloba* is 1.97 mm. Comparing with values from the literature indicates that *G. biloba* has a tracheid length higher than the value observed for *Eucalyptus camaldulensis* (stem and branch), lower than the *Pinus sylvestris* L., *Picea abies* (L.) H. Karst, and *Pinus halepensis* Mill. (stem wood) and close to the value of *P. halepensis* (branch wood). The mean earlywood tracheid diameter for *G. biloba* is 34.93 µm. Comparisons with literature values show that *G. biloba* earlywood tracheid diameter is consistent with *P. sylvestris* and *P. abies*. The mean latewood tracheid diameter for *G. biloba* is 28.19 µm. The mean ray length in *G. biloba* is 124.8 µm. The range of ray lengths spans from 95 to 144 µm. In comparison with Aleppo pine (*P. halepensis*) grown in Turkey (Table 1), the recorded value for *G. biloba* is lower. These values can serve as a baseline for future studies on the wood of *G. biloba* anatomy.

Table 1. Tracheid length, earlywood and latewood tracheid diameter, and ray length of *G. biloba* wood.

Parameter	Mean	SE	SD	Min.	Max.	Values from literature
Tracheid length (mm)	1.97	0.26	2.03	1.43	17.40	*Pinus sylvestris* =1.4-4.4[1] *Picea abies* =1.7-3.7[1] *Pinus halepensis* (stem wood) =2.81[2] *Pinus halepensis* (branch wood) = 2.19[2] *Eucalyptus camaldulensis* (stem)= 0.86[2] *Eucalyptus camaldulensis* (branch)= 0.7[2]
Earlywood tracheid diameter (µm)	34.93	0.40	1.60	32.00	37.500	*P. sylvestris* =10-50[1]
Latewood tracheid diameter (µm)	28.19	0.49	2.01	24.00	32.00	*P. abies* =20-40[1]
Ray length (µm)	124.80	2.72	13.85	95.00	144.00	*P. halepensis* = 150-160[3]

SE= standard error of the mean, SD= standard deviation. [1] (Fengel and Wegener, 2011): values represent overall averages; [2] (Hassan et al., 2020); [3](Biricik and Akkemik, 2021).

Table 2. Density, tangential, radial, and longitudinal shrinkage (%) of *G. biloba* wood.

Parameter	Mean	SE	SD	Min.	Max.	Values from literatu
Density (g/cm^3)	0.49	0.0025	0.005	0.48	0.49	*P. halepensis (stem wood)* =0.55[1] *P. halepensis (branch wood)* = 0.57[1] *E. camaldulensis(stem)*= 0.63[1] *E. camaldulensis(branch)*= 0.66[1]
Tangential shrinkage (%)	6.70	0.02	0.04	6.66	6.75	*Pinus banksiana*=6.6[2] *Picea glauca*= 8.2[2]
Radial shrinkage (%)	4.10	0.05	0.12	3.98	4.21	*P. banksiana*=3.7[2] *P. glauca*= 4.7[2]
Longitudinal shrinkage (%)	0.30	0.01	0.02	0.28	0.31	-

SE= standard error of the mean, SD= standard deviation. [1] (Hassan et al., 2020); [2] (Alden, 1995).

Table 3. Cellulose, hemicellulose (%), lignin (%), extractives (%), and ash (%) of *Ginkgo biloba* wood.

Parameter (%)	Mean	SE	SD	Min.	Max.	Values from literature
Cellulose	45.39	0.15	0.26	45.1	45.6	*G. biloba (male)* = 43.2[1] *G. biloba (female)* = 42.1[1] *P. sylvestris* =52.2[2] *Casuarina cunninghamiana =41.9*[3] *P. halepensis* (stem wood) =45.32[3] *P. halepensis* (branch wood) = 41.93[3] *E. camaldulensis*(stem)= 49.21[3] *E. camaldulensis*(branch)= 43.51[3]
Hemicellulose	21.59	0.11	0.19	21.4	21.71	*C. cunninghamiana* =28.5[4]
Lignin	30.68	0.47	0.81	29.9	31.52	*G. biloba (male)* = 32.3[1] *G. biloba (female)* = 33.8[1] *P. sylvestris* =26.3[2] *C. cunninghamiana =29.59*[2] *P. halepensis* (stem wood) =25.78[3] *P. halepensis* (branch wood) = 26.82[3] *E. camaldulensis*(stem)= 19.60[3] *E. camaldulensis*(branch)= 21.98[3]
Total extractives	2.10	0.09	0.16	1.95	2.26	*C. cunninghamiana =11.55*[4] *P. halepensis* (stem wood) =4.17[3] *P. halepensis* (branch wood) = 7.41[3] *E. camaldulensis* (stem)= 11.44[3] *E. camaldulensis* (branch)= 15.72[3]
Ash (%)	0.24	0.02	0.04	0.2	0.28	*G. biloba* (male) = 0.8[1] *G. biloba* (female) = 0.5[1] *P. halepensis* (stem wood) =0.46[3] *P. halepensis* (branch wood) = 1.02[3] *E. camaldulensis* (stem)= 0.42[3] *E. camaldulensis* (branch)= 1.48[3]

SE= standard error of the mean, SD= standard deviation. [1] (Timell, 1960); [2] (Kollmann and Fengel, 1965); [3] (Hassan et al., 2020); [4] (Abdel-Aal et al., 2008).

Table 4. Modulus of elasticity (MOE), compressive strength, and hardness of *Ginkgo biloba* wood.

Parameter	Mean	SE	SD	Min.	Max.	Values from literature
MOE (N. mm^{-2})	4834.4	52.9	118.3	4665	4976.0	*P. banksiana* =9310[(1)] *P. glauca*= 9860[(1)]
Compressive strength (N. mm^{-2})	29.00	0.21	0.46	28.3	29.40	*P. banksiana*=39[(1)] *P. glauca*=35.7[(1)]
Hardness (N)	1229.2	13.7	30.7	1187.0	1265.0	*P. banksiana*=2530[(1)] *P. glauca*=2130[(1)]

SE= standard error of the mean, SD= standard deviation. [(1)] (Alden ,1995)

Physical properties

Table 2 shows the density values, tangential shrinkage, radial shrinkage, and longitudinal shrinkage. The recorded data indicated that *G. biloba* wood density. The mean density of *G. biloba* wood is 0.49 g/cm^3. Compared to the literature values, *G. biloba*'s wood density appears to be lower than that of *Pinus halepensis* (stem wood and branch wood) and *E. camaldulensis* (stem and branch). This suggests that *G. biloba* wood lies among the medium-density wood species, with a lighter and less dense microstructure composition. *G. biloba* wood demonstrates moderate shrinkage properties, with tangential shrinkage comparable to *Pinus banksiana* Lamb. and slightly lower than *Picea glauca* (Moench)Voss. Similarly, radial shrinkage in *G. biloba* falls within the observed range for both *Pinus banksiana* Lamb. and *Picea glauca*, indicating moderate radial shrinkage characteristics akin to these reference species. The mean longitudinal shrinkage of *G. biloba* wood is 0.3%, the low values suggest that wood experiences minimal longitudinal shrinkage.

Chemical compositions

The results of the chemical compositions of *G. biloba* wood are presented in Table 3. The mean percentages of cellulose, hemicellulose, and lignin were 45.39%, 21.59%, and 30.68%, respectively. The recorded value for cellulose percentage (45.39%) in this study is greater than that reported by Timell (1960) for *G. biloba* even for both male and female trees. The mean hemicellulose content in *G. biloba* wood is 21.59%, Comparison with literature values (Table 3) suggests that *G. biloba* has a lower hemicellulose content compared to *Casuarina cunninghamiana*. Hemicellulose, as a component of wood, contributes to its overall structure and properties. Lignin content is also reported to be lower than those reported by Timell (1960) for *G. biloba*. Comparative analysis with literature values reveals that the lignin content of *G. biloba* is higher than and *E. camaldulensis* stem wood, but lower than *Casuarina cunninghamiana* Miq. and *E. camaldulensis* branch wood. Lower total extractives content was observed compared with the reported value for *P. halepensis* (branch- and stem wood), *E. camaldulensis*, and *C. cuninghamiana* (Table 3) which are grown in Egypt. Ash content reported in this study (0.24%) is also lower than those reported for *G. biloba* (Timell 1960) and lower than those recorded for *P. halepensis* (branch- and stem wood) and *E. camaldulensis*.

Mechanical properties testing

The results of mechanical properties of *G. biloba* wood namely modulus of elasticity (MOE), compressive strength, and hardness are presented in Table 4. Their mean values were 4834.40 N.mm^{-2}, 29.04 N.mm^{-2}, and 1229.2 N, respectively. In comparison to the literature values, the MOE of *G. biloba* is notably lower than that of *Pinus banksiana* (9310 N.mm^{-2}) and *P. glauca* (9860 N.mm^{-2}), indicating a lower modulus of elasticity in *G. biloba* wood. The compressive strength of *G. biloba* is lower than that of *P. banksiana* (39 N.mm^{-2}) and *P. glauca* (35.7 N.mm^{-2}), suggesting a relatively lower resistance to compressive forces. The hardness of *G. biloba* is considerably lower than that of *P. banksiana* and *P. glauca*, given its comparatively lower modulus of elasticity, compressive strength, and hardness in comparison to reference species such as *Pinus banksiana* and *Picea glauca* (Moench)Voss. The obtained results suggest that *G. biloba* wood may not be well-suited for load-bearing purposes, given its comparatively lower MOE, compressive strength, and hardness in comparison to reference species such as *P. banksiana* and *P. glauca*. Future studies to compare the wood properties of stems and branches are needed to gain a comprehensive understanding of this important renewable resource for the wood industry in Egypt.

Based on the density and mechanical properties, the findings suggest that *G. biloba* wood may be suitable for crafting lightweight furniture and carpentry purposes, such as door and window frames, and cabinets, as well as various woodworking projects like bowls, carvings, or decorative items. In comparison with locally grown species in Egypt, such as *E. camaldulensis*, which is commonly used for pulp and papermaking, *G. biloba* is likely to provide better pulp and paper due to its low lignin content, high cellulose percentage, and long fibers. This long-fibered lignocellulosic source could be experimentally tested for fiberboard production in future studies. Therefore, it is considered a promising fiber source in Egypt. Based on these findings, it is recommended to extend the cultivation of *G. biloba* in various regions of Egypt, as it has shown success in coastal areas like Alexandria. Furthermore, considering the medicinal and environmental importance of this genus, its cultivation could yield further benefits.

G. biloba exhibited a high amplitude of tolerance to environmental stochasticity in Egypt in the past decade, mitigating many potential ecological risks (Bidak et al., 2022). The species is recommended in street plantings in many countries due to its resistance to urban conditions (Dmuchowski et al., 2019). The anticipated potential ecological impacts of *G. biloba* for cultivation are usually positive as it can tolerate the many destructive impacts producing its role in ecosystem goods and services under any environmental threats, producing O_2 and sequestrating of CO_2, lowering the temperature, filtering air, and acting as shelter for native fauna and flora.

The predictable negative impact as reported in the case of Bulgaria (Tomova et al., 2021)., *G. biloba* has been cultivated in Bulgaria since the end of the 19th century. Female trees are considered contaminants of the landscape because their ripe seeds have a strong odor and are not utilized. On the other hand, Tomova et al., (2021) proposed the solution that the seeds have an advantage not only being a source of phytochemicals, but also a source of macro-(proteins, fats, and carbohydrates) and micronutrients (trace elements, vitamins, amino acids, etc.). *G. biloba* forests are widely studied for their fruits' high medicinal, edible, and economic values with an increasing global demand for its fruits supply (Feng et al., 2023). Yun et al., (2000) stated that only 4.7% of Koreans are subjected to respiratory pollen allergies. *Ginkgo* pollen could cause clinical symptoms during its season by cross-reacting with the Immunoglobulin E (IgE) produced in response to other pollens in patients sensitized to multiple pollens. We can mitigate the impact by regular pruning, trimming, and announcements for susceptible patients during the pollen-shedding month. The tree may negatively affect native biodiversity especially if it is grown in the wild ecosystem, so planting will be restricted to streets and gardens.

CONCLUSION

According to the results, *Ginkgo biloba* wood can fill the gap in importing wood from abroad to Egypt and it can be used in paper making and general furniture and carpentry applications. Despite the limited number of tested trees of *G. biloba* in this study, we recommend the cultivation of this species along the Mediterranean coast of Egypt since the climate is suitable with an appropriate precipitation range between 100 and 150 mm/year. This will entail primarily testing the performance of *G. biloba* in experimental fields along the coast with different soil physicochemical characteristics. We can use the treated wastewater in the Mediterranean coastal cities in Egypt to cultivate *G. biloba*. Furthermore, the recommended cultivation of *G. biloba* can also be directed towards the production of economic and medicinal components from leaves and fruits. Accordingly, we conclude that the cultivation of *G. biloba* in Egypt will represent an added value to the Egyptian circular economy. This study may represent baseline data and a starting point for more research on *G. biloba* in Egypt. Our study introduces baseline data for many specific future research areas such as (but not exclusive to) the effect of different soil types and irrigation treatments on the growth of the species in Egypt, testing the quality of the cellulose paste extracted from the plant in paper making, and the effect of the various temperature ranges in Egyptian cities on the growth opportunities of the plant, etc.

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REFERENCES

Abdel-Aal, M., Mohareb, A., Shetta, N. (2008) Evaluation of sewage sludge applications on chemical composition of *Casuarina cunninghamiana* wood. Journal of Agricultural Science, *Mansoura University*, 33 (7): 5197-5208.

Abdel Razik, M. S., El Gareeb, R., Heneidy, S.Z., Bidak, L. M. (1996) "A Guide to the plants of the Omayed Biosphere Reserve, Value and Potential Uses", submitted to *Egyptian Environment Affairs Agency,* 97 pp.

Alden, H. A. (1995) Hardwoods of North America. General Technical Report FPL-GTR-83. USDA Forest Service Forest Products Laboratory, Madison, Wis.

ASTM D1102-84 (2013). “Standard test method for ash in wood,” ASTM International, West Conshohocken, PA, USA.

ASTM D1105-96 (2013) “Standard test method for preparation of extractive-free wood,” ASTM International, West Conshohocken, PA, USA.

ASTM D1106-96 (2013) “Standard test method for acid-insoluble lignin in wood,” ASTM International, West Conshohocken, PA, USA.

ASTM D2395 (2002) “Standard test methods for density and specific gravity (relative density) of wood and wood-based materials,” ASTM International, West Conshohocken, PA, USA.

Balaganesh, B., Murali, S., Induja, D. K. (2022) Carbon sequestration potential of oak trees. Compendium of Agriculture and Allied Sciences, 215pp.

Bidak, L. M., Heneidy, S. Z., Halmy, M. W. A., El-Kenany, E. T. (2022) Sustainability potential for *Ginkgo biloba* L. plantations under climate change uncertainty: An ex-situ conservation perspective. *Acta Ecologica Sinica*, 42(2), 101-114.

Biricik, Y., Akkemik, Ü. (2021) Wood anatomy of Aleppo pine (*Pinus halepensis* Miller) grown naturally in Turkey. *Eurasian Journal of Forest Science*, 9(3), 175-186.

Boulos, L. (2009) "*Flora of Egypt: Checklist*. Cairo, Egypt: Al Hadara Publishing, 410 pp.

BS 373 (1957) British standard: Methods of testing small clear specimens of timber. British Standard Institution, London.

Cao, J., Wang, H., Zhang, W., Cao, F., Ma, G., Su, E., (2018) Tailor-made deep eutectic solvents for simultaneous extraction of five aromatic acids from *Ginkgo biloba* leaves. Molecules 23. https://doi.org/10.3390/molecules23123214.

Chavan, B. L., Rasal, G. B. (2011) Sequestered carbon potential and status of *Eucalyptus* tree. *International Journal of applied engineering and technology*, 1(1), 41-47.

Cheng Wan-chün, Fu Li-kuo. (1978) Ginkgoaceae. In: *Cheng Wan-chün & Fu Li-kuo, eds*., Fl. Reipubl. Popularis Sin. 7: 18-23.

Dmuchowski, W., Brągoszewska, P., Gozdowski, D., Baczewska-Dabrowska, A. B., Chojnacki, T., Jozwiak, A., Swiezewska, E., Gworek, B., Suwara, I. (2019) Strategy of *Ginkgo biloba* L. in the mitigation of salt stress in the urban environment. Urban *Forestry & Urban Greening*, 38, 223–231. https://doi.org/10.1016/j.ufug.2019.01.003.

Fang, J., Wang, Z., Wang, P., Wang, M., (2020) Extraction, structure and bioactivities of the polysaccharides from *Ginkgo biloba*: a review. International *Journal of Biological Macromolecules*, 162, 1897–1905. http://10.1016/j.ijbiomac.2020.08.141.

Farahat, E., Shaltout, K., El-Kady, H., Shalapy, A. (2012) Allometric equations to predict the total aboveground biomass of tree species in a planted forest in Egypt. *Feddes Repertorium*, 123(1), 27-36.

Feng, L., Sun, J., El-Kassaby, Y. A., Luo, D., Guo, J., He, X., Zhao, G., Tian, X., Qiu, J., Feng, Z., Wang, T., Wang, G. (2023) Planning Ginkgo biloba future fruit production areas under climate change: Application of a combinatorial modeling approach. *Forest Ecology and Management*, 533, 120861. https://doi.org/10.1016/j.foreco.2023.120861.

Fengel, D., Wegener, G. (Eds.). (2011) Wood: chemistry, ultrastructure, reactions. Walter de Gruyter.

Fritts HC (2001) Tree rings and climate. Blackburn Press, Caldwell.

Gärtner, H., Schweingruber, F. H. (2013) Microscopic preparation techniques for plant stem analysis. (*Remagen*: Verlag Dr. Kessel), 78pp.

Grissino-Mayer, H., (2001) Evaluating Crossdating Accuracy: A Manual and Tutorial for the Computer Program COFECHA. *Tree-Ring Research*, 57, 205–221.

Guo, J., Wu, Y., Wang, G., Wang, T., Cao, F., (2020) Integrated analysis of the transcriptome and metabolome in young and mature leaves of *Ginkgo biloba*. *Indian Crops Production*, 143, 111906. http://10.1016/j.indcrop.2019.111906.

Guo, S. Y., Wang, K. M., Peng, L. C., Yan, H., Zhou, N. (2020) Selection of carbon sink tree species based on natural distribution of ancient trees. *Hubei Forest Science Technolology*, 49, 37-41.

Hassan, K. T., Horáček, P., Tippner, J. (2013) Evaluation of stiffness and strength of scots pine wood using resonance frequency and ultrasonic techniques. *BioResources*, 8(2), 1634-1645.

Hassan, K., Kandeel, E., Kherallah, I., Abou-Gazia, H., Hassan, F. (2020) *Pinus halepensis* and *Eucalyptus camaldulensis* grown in Egypt: A comparison between stem and branch properties for pulp and paper making. *BioResources*, 15(4), 7598.

Heneidy, S. Z. (2010) *The Plant Atlas of the Botanic Garden (ALEX)*. Monchaa El-Maaref, 632 pp.

Heneidy, S. Z., Al-Sodany, Y. M., Fakhry, A. M., Bidak, L.M., Kamal, S. A., Halmy, M.W.A., El Kanany, E. T., Toto, S. M. (2024a) New Records and Endemic Taxa Revealed in The Novel Checklist of Alexandria Flora: Implications for Conservation Prioritization. *Egyptian Journal of Botany*, 64, 1, 387-418. doi: 10.21608/ejbo.2023.224043.2413

Heneidy, S. Z., Al-Sodany, Y. M., Fakhry, A. M., Kamal, S. A., Halmy, M.W.A., Bidak, L.M., El Kanany, E. T., Toto, S. M. (2024b) Biology of *Nicotiana glutinosa* L., a newly recorded species from an archaeological excavation site in Egypt. *BMC Plant Biology,* 24, 148. https://doi.org/10.1186/s12870-024-04816-z

Heneidy, S. Z., Bidak, L. M., Halmy, M. W. A. Fakhry, A. M., Toto, S. M, El Kanany, E. T. (2024c) Naturalization and invasion potential of *Sesuvium portulacastrum* L. recorded as alien species in Egypt. *Scientific Reports* **14**, 3117. https://doi.org/10.1038/s41598-024-53627-7

Hill, C. A., Papadopoulos, A. N. (2001) A review of methods used to determine the size of the cell wall microvoids of wood. *Journal of the Institute of Wood Science*, 15, 337–345.

Husch, B., Beers, T. W., Kershaw J, J. A. (2002) Forest mensuration. John Wiley and Sons.

IAWA Committee (2004) IAWA list of microscopic features for softwood identification. IAWA-Journal 25 (1): 1–70.

ISO 13061-13 (2016) “Physical and mechanical properties of wood – Test methods for small clear wood specimens – Part 13: Determination of radial and tangential shrinkage,” International Organization for Standardization, Geneva, Switzerland.

Kollmann, F., Fengel, D. (1965) Changes in the chemical composition of wood by thermal treatment. Holz als Roh-und Werkstoff, 23, 461-468.

Kürschner, K., Hoffer, A. (1929) “Ein neues Verfahren zur Bestimmung der Cellulose in Hölzern und Zellstoffen. Technologie und Chemie der Papier- und Zellstoff-Fabrikation 26, 125-129.

Lee, P. W. Eom, Y. (1987) Wood Identification of the Veneer Species that grow in Korea - II. Wood Characteristics and Identification by Microscopic Features. *Journal of the Korean Wood Science and Technology,* Vol. 15 (1), 22-55.

Long, P., Ren, L., Fang, C., Feng, Y., Luo, Y., (2016) Antifeedant activity of *Ginkgo biloba* secondary metabolites against *hyphantria cunea* larvae: mechanisms and applications. *PLoS One* 11, e0155682. http://10.1371/journal.pone.0155682.

Ma, J., Ma, N. L., Zhang, D., Wu, N., Liu, X., Meng, L., Li, M. (2022) Zero waste multistage utilization of *Ginkgo biloba* branches. *Chemosphere*, 292, 133345.

Meng, F. (2023) Potential Carbon Sequestration and Economic Value Assessment of the Relict Plant *Ginkgo biloba* L. Based on the Maximum Entropy Model. *Forests*, 14, 1618.

MSEA (Ministry of State for Environmental Affairs) (2004) Afforestation: the role of Ministry of state for Environmental Affairs in implementing the national program for safe use of treated sewage water for afforestation. *Annual report*, 60–69.

Nowak, D. J., Crane, D. E. (2002) Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution,* 116(3), 381-389.

Ogren, T. L. (2000) Allergy-free gardening. The revolutionary guide to healthy landscaping.

POWO. (2024) *Ginkgo biloba* L. Plants of the World Online. http://powo.science.kew.org

Rashed, S. A., Eldarier, S. M., El-Sheikh, A. A., Toto S, M. (2022) Ethno-phytotechnology of Tribulus terrestris L. (Zygophyllaceae). *Egyptian Journal of Botany*, 62, 2, 561-573. doi: 10.21608/ejbo.2022.114629.1874

R Core Team (2021) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Royer, D. L., Hickey, L. J., Wing, S. L. (2003) Ecological conservatism in the “living fossil” *Ginkgo*. *Paleobiology*, 29(1), 84-104.

Sati, P., Pandey, A., Pandey, L., (2012) Antimicrobial potential of leaf extracts of *Ginkgo biloba*. Growing in Uttarakhand, India. *National Academy Science Letters*, 35, 201–206. http://10 .1007/s40009-012-0036-8.

Scott, R. A., Barghoorn, E. S., Prakash, U. (1962) “Wood of Ginkgo in the tertiary of western North America,” *American Journal of Botany*, 49(10), 1095-1101. DOI: 10.2307/2439157.

Shaltout, K., Bedair, H. (2022) Diversity, distribution, and regional conservation status of the Egyptian tree flora. *African Journal of Ecology*, 60(4), 1155-1183.

Singh, B., Kaur, P., Singh, R. D., Ahuja, P. S. (2008) Biology and chemistry of *Ginkgo biloba*. *Fitoterapia*, 79(6), 401-418.

Timell, T. E. (1960) Studies on *Ginkgo biloba*, L. 1. General characteristics and chemical composition. *Svensk Papperstidning*, 63(19), 652-7.

Tomova, T., Slavova, I., Tomov, D., Kirova, G., Argirova, M. D. (2021) Ginkgo biloba Seeds—An Environmental Pollutant or a Functional Food. *Horticulturae*, 7(8), Article 8. https://doi.org/10.3390/horticulturae7080218.

Toochi, E. C. (2018) Carbon sequestration: how much can forestry sequester CO_2. Forestry Research and Engineering: *International Journal*, 2(3), 148-150.

Trading Economics. (2024) *Egypt Imports of Wood and articles of wood, wood charcoal—2024 Data 2025 Forecast 1994-2022 Historical*. https://tradingeconomics.com/egypt/imports/wood-articles-wood-wood-charcoal

Wang, L., Cui, J., Jin, B., Zhao, J., Xu, H., Lu, Z., Lin, J. (2020) Multifeature analyses of vascular cambial cells reveal longevity mechanisms in old *Ginkgo biloba* trees. *Proceedings of the National Academy of Sciences*, 117(4), 2201-2210.

Wang, L., Liu, J., Liu, J., Wei, H., Fang, Y., Wang, D., Chen, R., Gu, W. (2023) Revealing the long-term trend of the global-scale *Ginkgo biloba* distribution, and the impact of future climate change based on the ensemble modeling. *Biodiversity and Conservation*, 32(6), 2077–2100. https://doi.org/10.1007/s10531-023-02593-z

Xu, B., Mitchell, N. (2011) Carbon sequestration by trees on the city campus unpublished working paper, *The University of Auckland*, Auckland.

Xu, S.L., Choi, R., Zhu, K.Y., Leung, K.W., Guo, A., Bi, D., (2012) Isorhamnetin, A flavonol aglycone from *Ginkgo biloba*, induces neuronal differentiation of cultured PC12 cells:

potentiating the effect of nerve growth factor. Evidence-Based Complementary and Alternative Medicine, 1–11. http://10 .1155/2012/278273.

Yun, Y.-Y., Ko, S.-H., Park, J.-W., Hong, C.-S. (2000) IgE immune response to Ginkgo biloba pollen. *Annals of Allergy, Asthma & Immunology,* 85(4), 298–302. https://doi.org/10.1016/S1081-1206(10)62533-1.

Zahran, M., El-Ameir, Y. (2012) On the ecology and propagation of the wood producing trees and shrubs in the Egyptian deserts. *Cepaea nemoralis* L. Journal of Ecology, 56(2), 405–442.

Zhang, X., He, P., Guo, L., Meng, F. (2023) Potential Carbon Sequestration and Economic Value Assessment of the Relict Plant *Ginkgo biloba* L. Based on the Maximum Entropy Model. Forests, 14(8), 1618.

Zu, K., Wang, Z., Zhu, X., Lenoir, J., Shrestha, N., Lyu, T., Luo, A., Li, Y., Ji, C., Peng, S., Meng, J., Zhou, J. (2021) Upward shift and elevational range contractions of subtropical mountain plants in response to climate change. *Science of The Total Environment*, *783*, 146896. https://doi.org/10.1016/j.scitotenv.2021.146896.