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Study of Some Mechanical and Physical Properties of Wood of Some Selected Tree Species in Sulaimaniyah Governorate, North Iraq.

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ABSTRACT
Timber trading and pricing are primarily influenced by the mechanical and physical properties of wood. Different parameters of the wood including compressive strength, hardness, and wood density determine the quality of the timber. This study investigates the mechanical and physical characteristics of five selected tree species: *Eucalyptus camaldulensis*, *Populus nigra*, *Melia azedarach*, *Paulownia tomentosa* and *Gleditsia triacanthos*. The samples were sourced from the Agricultural Engineering College, and prior to the tests, confirmed to be free from defects and diseases. Mechanical testing revealed that the direction of applied force, whether parallel (P_0) or perpendicular (P_{90}) to the wood grain, significantly impacts compressive strength. The compressive strength values ranged from the highest for *Eucalyptus camaldulensis* (55.4 MPa) to the lowest for *Paulownia tomentosa* (25 MPa). Hardness values varied across species, with the highest observed in Gleditsia triacanthos (2758 N) and the lowest in *Paulownia tomentosa* (1016 N). The study classified the wood hardness into four categories: Very Soft Wood, Hardwood, Softwood, and Medium Hardwood, based on compressive strength. *Eucalyptus camaldulensis* exhibited the highest density (0.9 g/cm³), while *Paulownia tomentosa* had the lowest (0.3 g/cm³). Moisture content also varied, with *Eucalyptus camaldulensis* showing the highest moisture content (77.21%) and *Gleditsia triacanthos* the lowest (48.1%). The findings suggest that *Paulownia tomentosa* is particularly suited for the wood carving industry. At the same time, *Eucalyptus camaldulensis* and *Gleditsia triacanthos* offer stronger timber, making them more suitable for diverse structural applications.

***Keywords*:** *Mechanical properties; Compressive strength; Hardness; Wood utilization; Physical properties*.

INTRODUCTION

Wood, an organic and naturally occurring material, has been used in construction for centuries, utilized in buildings, bridges, and numerous other structures [1]. Its significance in the construction industry persists due to its renewable nature and low energy consumption requirements [2]. The utilization of timber in construction has experienced significant growth globally in recent decades, driven by its lightweight properties and minimal environmental impact [3,4]. However, utilizing wood depends on wood quality and this mainly depends on its mechanical and physical properties such as its compressive strength, hardness and density [5,6,7]. Each type of wood has its distinct strength that required to measure separately. As an orthotropic material, wood exhibits unique characteristics along the longitudinal, radial and tangential axes, each with distinct mechanical properties. [8,9].

While the wood industry in Iraq has seen recent expansion, the production of timber remains limited and economically insignificant due to the absence of woodland and reduction of forest cover as a result of climate change in the Mediterranean region [10,11,12]. Consequently, the local wood industry primarily confined to furniture production and firewood, while the construction sector heavily reliant on imported timber [7]. In Sulaimaniyah Governorate, several tree species are currently utilized for timber including *Eucalyptus camaldulensis*, *Populus nigra*, *Melia azedarach*, *Paulownia tomentosa*, and *Gladitisia triacanthos*). However, wood selection for construction requires meticulous consideration. To ensure structural integrity and durability, it is crucial to select timber free from defects such as rot, warp, knots, fungal infestations, and mildew [10]. In the past decade, various tree species, including *Paulownia tomentosa*, *Melia azedarach*, *Albizia julibrissin*, and *Gleditsia triacanthos*, have been introduced and planted in the Kurdistan Region of Iraq, as ornamental trees along streets and in parks [3,4,14]. However, some of these introduced species have exhibited poor adaptability to the Mediterranean climate of the Kurdistan Region, trees will either uproot or stem breakage during windstorms due to weak mechanical properties [12]. In this study, five of the most common species selected for mechanical and physical properties assessment include compressive strength, hardness and density. Categorize the timber based on its compressive strength. Lastly, recommend the ideal tree species to plant depending on the intended use. The findings of this study will provide valuable insights for government agencies and farmers, enabling them to select and cultivate tree species that are both economically viable for the wood industry and well-adapted to the climatic conditions of Sulaimaniyah City.

MATERIALS AND METHODS

Climatological Conditions

The study area is located at an elevation of 743 to 750 meters above sea level (a.s.l.). The average annual rainfall of 650mm indicates that the area is relatively dry, with the precipitation potentially occurring mostly during the wetter seasons (e.g., winter or spring). With an average annual potential evapotranspiration of 1500mm, the region experiences a high rate of water loss through both evaporation and plant transpiration [16,17].

Sampling

Five different species of tree (*Eucalyptus camaldulensis*, *Populus nigra*, *Melia azedarach*, *Paulownia tomentosa*, and *Gladitisia triacanthos*) selected for this study from Sulaimani City to represent the same climatological condition and share same topographic elevation which is 743m above mean sea level (a.s.l). The selected wood branches were nearly of the same thickness 50mm. The saw machine was used to cut the samples at a length of 50mm. Timber specimens prepared according to specific dimensions and requirements and have the same cross-section area of 50mm * 50mm *50mm. Six samples for each species tested to determine its the physical and mechanical properties.

Compressive strength test

The wood specimen is put in a universal testing machine between two compression platens. To evaluate the wood's compressive strength, we applied load in two different ways: first, parallel to the wood grain(P_0) until the specimen broke, and second, perpendicular to the wood grain(P_{90}) until the specimen broke [15] (Figure 1). Usually, the compressive strength is given in force per unit area.

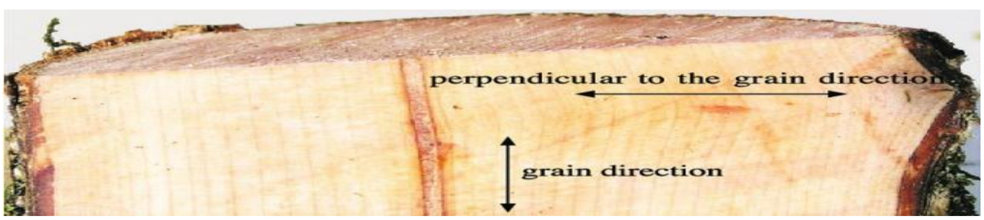
$P_{0,90}$= F (Mn) / A (m^2) ………………..(1) [16].

Where P_0 is parallel to grain (0) or P_{90} perpendicular to grain, F force (KN), A cross-sectional area (m^2) (Figure 2).

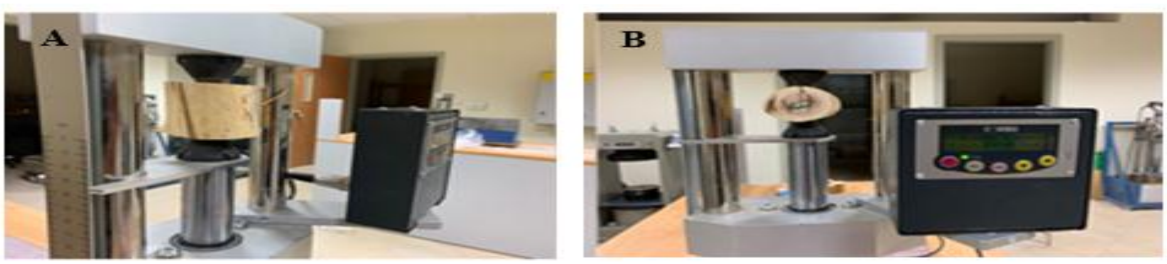
Hardness

test is the force necessary to embed an 11.28 mm steel ball into wood until the ball's diameter is half is measured, is measured in a lab [5]. This method known as the Janka hardness test, shows which types of wood are harder than others [17]. We can use the following equation to determine the Janke hardness value Hj=(F)/(A) ……………………….…(2) [16].

HJ is the Janka hardness (N/mm^2), F is the applied loading force (N), and A is the indentation area.



(Figure 1): Grain directions on a tree [19]



(Figure 2): Determine the compressive strength of timber (A) P_0 and (B) P_{90}

Density

The weight of the fresh and dry branches was then measured using an electronic balance, and the following formula (Eq. 3) was applied:

Density $= \frac{\text{Sample weight (g)}}{\text{Sample volume (cm}^3\text{)}}$ …(3) [18].

To find the density of the wood, we used a ruler to measure the length and cross-section of the weights specimen, which enabled us to calculate its volume (Figure 3).

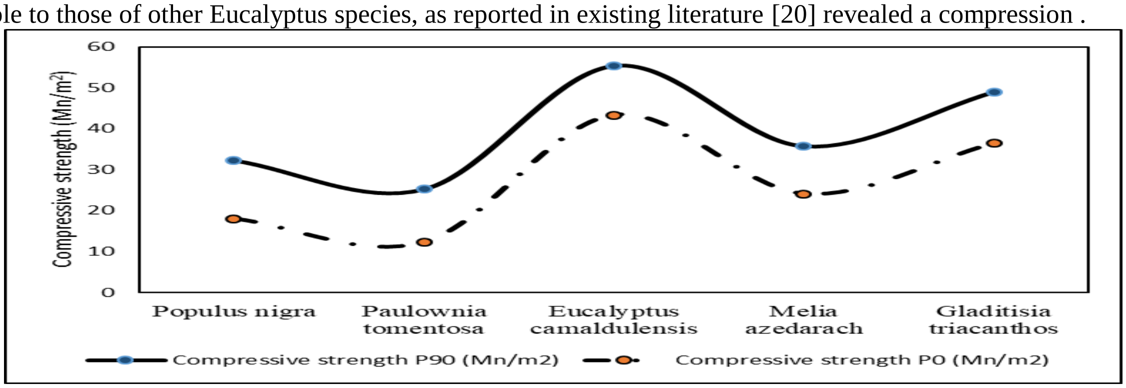
Moisture content

The moisture contained was calculated as the difference between the of the specimens. At first, the wet specimens (green weight) were directly measured by a sensitive electronic balance, and then the dry weight of the specimens was recorded after oven drying at 103C° until they reached a constant weight, then the following formula (Eq.4):

$MC = \frac{\text{Green weight} - \text{Dry weight}}{\text{Dry weight}}$ *10. (4) [19] Where MC is the moisture content.

Results and Discussions

The mechanical property of timber is a basic parameter for determining timber classes based on its strength. Strength represents the quality of timber to resist rupture or bending. The tested species' compression strength results are illustrated in the following accompanying show in (Figure 4). The lowest compression strength was seen in the *Paulownia tomentosa* species, which had a value of (25.3 Mn/m^2), while the *Eucalyptus camaldulensis* species demonstrated the highest compression strength of (55.4 Mn/m^2). The compression strength properties of *Eucalyptus. camaldulensis* woods were comparable to those of other Eucalyptus species, as reported in existing literature [20] revealed a compression .



(Figure 4): Compressive strength of five species of tree samples P_0 and P_{90} (Mn/m^2)

strength of 50.40 MPa for *Eucalyptus bicostata*. Additionally, [21] reported compression test values of 56.3 MPa and 56.9 MPa for *Eucalyptus loxophleba* and *Eucalyptus salmonophloia* woods, respectively. According to [22], this species (*Eucalyptus camaldulensis*) is categorized as having medium compressive strength.Tree samples are classified and employ a standardized scale to categorize six class hardness of various wood species based on [23]. This scale consists of six distinct classes, ranging from extremely soft wood (class I) to unbelievably hardwood (class VI), allowing classification of wood hardness based on compressive strength for samples that are subject to perpendicular stress as shown in (Table 1), and also for samples that subject to parallel stress (Table 2). According to (Table 1) *Paulownia tomentosa* (25.3 Mn/m^2) is located in class I very softwood, and *Gladitisia triacanthos* species has (49 Mn/m^2) located in class III medium hardwood. According to (Table 2) *Populus nigra*, *Paulownia tomentosa*, and *Melia azedarach* have (18 Mn/m^2, 12.3 Mn/m^2, and 24.1 Mn/m^2) compressive strength (P_{90}) respectively classify them as very soft wood wheal *Eucalyptus camaldulensis* and *Gladitisia triacanthos* species have (43.3 Mn/m^2, 36.4 Mn/m^2) respectively it located in softwood class.

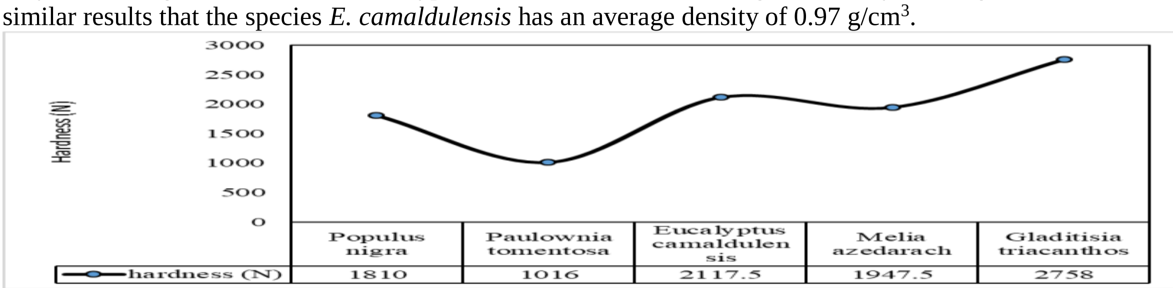
(Table 1): Standard scale for determining the hardness of wood sample subjected to P_{90}[23].

Species name	Classes	Hardness	Range (MPa)	Sample Compressive strength (P90)	Hardness
Populus nigra	I	Very soft wood	under 34.3	32.3	Very soft wood
Paulownia tomentosa	II	Soft wood	34.3 - 49.0	25.3	Very soft wood
Eucalyptus camaldulensis	III	Medium hardwood	49.1- 63.7	55.4	Medium Hardwood
Melia azedarach	IV	Hardwood	63.7- 98.1	35.8	Softwood
Gladitisia triacanthos	V	Very hard wood	98.1–147.1	49.2	Medium Hardwood

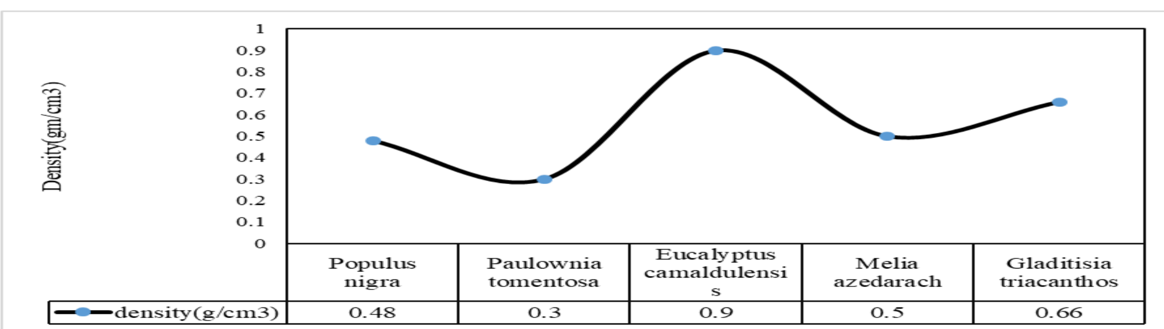
(Table 2): Standard scale for determining the hardness of wood samples that are subjected to P_0[23]

Species name	Class	Hardness	Range MPa	Sample Compressive strength (P0)	Hardness
Populus nigra	I	Very soft wood	under 34.3	18	Very soft wood
Paulownia tomentosa	II	Soft wood	34.3-49.0	12.3	Very soft wood
Eucalyptus camaldulensis	III	Medium hardwood	49.0-63.7	43.3	Softwood
Melia azedarach	IV	Hardwood	63.7-98.1	24.1	Very soft wood
Gladitisia triacanthos	V	Very hard wood	98.1-147.1	36.4	Softwood

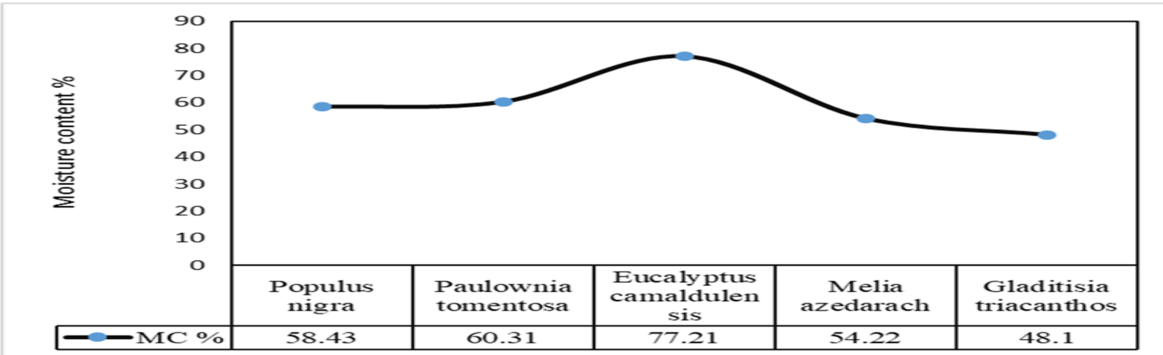
(Figure 5). shows the hardness results for the tested species, among them the species *Paulownia tomentosa* had the lowest hardness (1650 N), while *Gladitisia triacanthos* species performed the highest hardness (2758 N). Paulownia wood's comparatively low hardness is attributed to its porous nature, which results from the rapid annual growth of the Paulownia tree. This distinguishes it from other wood types [23]. wood density is the weight of wood in grams per cubic centimeter at a specific moisture content [18]. The densities of different samples have been measured and presented (Figure 6). It is clear from the results that the densities of the samples varied significantly. Among the samples, *Paulownia tomentosa* had the lowest density of 0.3 g/cm^3, compared to other research as reported in the literature the density of *Paulownia tomentosa* is very low 0.27 g/cm^3 [24]. while *Eucalyptus camaldulensis* had the highest density of 0.9 g/cm^3, the research [25] revealed similar results that the species *E. camaldulensis* has an average density of 0.97 g/cm^3.



(Figure 5): The hardness of five different species (Newton)



(Figure 6): The measured density of tree species



(Figure 7): The measured moisture contains trees species

moisture content of samples has been calculated and shown in (Figure 7). Among the results, *Eucalyptus camaldulensis* had the highest value (77.21%), which was near to the results reported by [4,25], which are (75.14%) and (89.46%) respectively and lower moisture contain (48.1%) recorded by *Gleditsia tricanthos* that is close to the result obtained by [26] which is (36.19%). The relationship between timber density, moisture content, hardness, and compressive strength significantly influences the appropriateness of various wood species for different uses. To assess which species are more suitable for use based on the given characteristics, we can examine the various aspects of each species: *Eucalyptus camaldulensis* exhibits the greatest density at (0.9 g/cm³) which aligns with the finding [27]. Their research characterizes *Eucalyptus camaldulensis* as a high-density wood, a trait typically associated with enhanced strength, while *Gleditsia triacanthos* has the greatest hardness (2758 N), making it exceptionally resistant to indentation and abrasion it also has the lowest moisture content (48.1%), which enhances its dimensional stability and decay resistance this aligns with the findings of [28] that illustrate as moisture content decreases, wood strength and hardness increase, Among the species tested, *Eucalyptus camaldulensis* demonstrates the greatest compressive strength at 55.4 MPa, suggesting its superior ability to resist failure under heavy loads**.**

Conclusion:

Various timbers have gained economic value in timber utilization marketing in recent years. Farmers have invested poorly in planting tree species in Iraq, without focusing on their mechanical and physical properties. This study in the Sulaimani governorate tested five common tree species: *Eucalyptus camaldulensis*, *Populus nigra*, *Melia azedarach*, *Paulownia tomentosa*, and *Gladitisia triacanthos*. The Results demonstrated significant variations in compressive strength across species and with the direction of applied force. *Eucalyptus camaldulensis* exhibited the highest compressive strength (55.4 Mn/m^2), followed by *Gleditsia triacanthos* (49 Mn/m^2), while *Paulownia tomentosa* demonstrated the lowest (25 Mn/m^2). *Gleditsia triacanthos* exhibited the highest hardness (2758 Newton) and a moderate moisture content (48.1%), suggesting good stability and durability for various applications. *Eucalyptus camaldulensis* and *Populus nigra* wood are recommended for high strength wood products industry, while Paulownia is not recommended for load-bearing structures. *Melia azedarach* and *Paulownia tomentosa* may be better suited for the carving industry due to their lower strength and potentially easier workability. Furthermore, the study highlights the importance of considering mechanical properties when selecting trees for urban environments. The susceptibility of *Melia azedarach* to wind damage underscores the need for careful species selection to ensure the safety and longevity of urban trees. Based on our findings, *Eucalyptus camaldulensis* and *Gleditsia triacanthos* demonstrate beater mechanical properties and may be more suitable for use for wood columns, tools and local furniture.

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دراسة بعض الخصائص الميكانيكية والفيزيائية للأخشاب لبعض أنواع الأشجار المختارة في شمال العراق.

هيفي شوكت إبراهيم

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الخلاصة

تؤثر الخصائص الميكانيكية والفيزيائية للخشب على جودتها وبالتالي على المردود الاقتصادي. تحدد الخصائص المختلفة للخشب بما في ذلك قوة الضغط والصلابة وكثافة الخشب على جودة الاخشاب. هدفت الدراسة الخصائص الميكانيكية والفيزيائية لخمسة أنواع مختارة من الأشجار *Eucalyptus : camaldulensis*و *Populus nigra* و *Melia azedarach* و *Paulownia tomentosa* و *Gleditsia triacanthos* جمعت العينات من كلية الهندسة الزراعية ، بعد التأكد من خلوها من العيوب والأمراض. اظهرت نتائج الاختبار الميكانيكي أن اتجاه القوة المطبقة، سواء كانت موازية *(P0)* أو عمودية *(P90)* على ألياف الخشب، يؤثر بشكل كبير على قوة الضغط. تراوحت قيم قوة الضغط من أعلى قيمة لـ *Eucalyptus camaldulensis* (55.4 ميجا باسكال) إلى أدنى قيمة لـ *Paulownia tomentosa* (25ميجا باسكال). وتباينت قيم اختبارالصلابة بين الأنواع، حيث سجلت أعلى قيمة لها *Gleditsia triacanthos* (2758نيوتن) وأدنى قيمة لها *Paulownia tomentosa* (1016 نيوتن). وصنفت الدراسة صلابة الخشب إلى أربع فئات: الخشب اللين جدًا، والخشب الصلب المتوسط، والخشب اللين، والخشب الصلب المتوسط، بناءً على قوة الضغط. وأظهر *Eucalyptus camaldulensis* أعلى كثافة (0.9 غم/سم3)، بينما سجل *Paulownia tomentosa*أدنى كثافة (0.3 غم/سم3). كما تباين المحتوى الرطوبي، حيث أظهر *Eucalyptus camaldulensis* أعلى محتوى للرطوبة (77.21٪) وأدنى محتوى رطوبى كانت لاشجار *Gleditsia triacanthos* بقيمة 48% .وبناء على هذه النتائج يمكن الاشارة إلى أن اشجار *Paulownia tomentosa* مناسبة بشكل خاص لصناعة النحت الخشبي، في حين توفر اشجار *Eucalyptus camaldulensis* و *Gleditsia triacanthos*أخشابًا ذات خصائص افضل ، مما يجعلها أكثر ملاءمة للتطبيقات الهيكلية المتنوعة وبسبب خصائصها الميكانيكية قد تكون أكثر ملاءمة للاستخدام وللتشجير في المناطق الحضرية.

الكلمات المفتاحية: الخصائص الميكانيكية، قوة ضاغطة، الصلابة، استثمار الخشب، الخصائص الفيزيائية.