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Paulownia Cultivation in Libya: Soil Improvement, Growth Potential, and Economic Benefits: A Review Article

Mohamed Ali A Salim *
Department of Plant Production, Faculty of Agriculture, Sirte University, Sirte, Libya
mohamed.salim@su.edu.ly

زراعة الباولونيا في ليبيا:
تحسين التربة، إمكانات النمو، والفوائد الاقتصادية – مقالة مراجعة

محمد علي عبدالسلام سالم *
قسم الإنتاج النباتي ، كلية الزراعة ، جامعة سرت، سرت ، ليبيا

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Abstract:
Paulownia tomentosa, known as the empress tree, is a fast-growing species native to China. This study reviews its botanical characteristics, environmental and economic benefits, agricultural applications, and cultivation challenges.The tree improves soil quality and water retention while effectively sequestering carbon dioxide, making it valuable for climate change mitigation. Its lightweight timber is commercially useful, and its leaves serve as a high-protein livestock feed, promoting sustainable agriculture. In Libya, Paulownia tomentosa can enhance agricultural productivity through reforestation and soil quality improvement. However, challenges include uncontrolled spread and susceptibility to pests and diseases. The research emphasizes developing management strategies to address these issues and ensure sustainability.

Keywords: tomentosa, Sustainable agriculture, Soil improvement, Carbon sequestration, Reforestation, Libya.

الملخص:
تُعرف*Paulownia tomentosa* ، أو شجرة الإمبراطورة، بأنها نوع سريع النمو موطنه الأصلي الصين. تستعرض هذه الدراسة خصائصها النباتية، وفوائدها البيئية والاقتصادية، وتطبيقاتها الزراعية، بالإضافة إلى التحديات المرتبطة بزراعتها. تساهم هذه الشجرة في تحسين جودة التربة وتعزيز احتفاظها بالمياه، كما أنها تلعب دورًا فعالًا في احتجاز ثاني أكسيد الكربون، مما يجعلها ذات قيمة في التخفيف من تغير المناخ. يتميز خشبها بخفة الوزن وقيمته التجارية العالية، بينما تُستخدم أوراقها كعلف غني بالبروتين للماشية، مما يدعم الزراعة المستدامة. في ليبيا، يمكن أن تعزز *Paulownia tomentosa* الإنتاجية الزراعية من خلال إعادة التشجير وتحسين جودة التربة. ومع ذلك، تشمل التحديات المرتبطة بزراعتها انتشارها غير المنضبط

وقابليتها للإصابة بالآفات والأمراض. تؤكد هذه الدراسة على أهمية تطوير استراتيجيات إدارة فعالة لمواجهة هذه التحديات وضمان الاستدامة.

الكلمات الدالة: *Paulownia tomentosa*، الزراعة المستدامة، تحسين التربة، احتجاز الكربون، إعادة التشجير، ليبيا.

Introduction

Paulownia tomentosa, commonly known as the empress tree or princess tree, is a fast-growing deciduous tree native to China. Its rapid growth rate and versatile benefits have led to its global spread, making it an attractive option for reforestation, soil improvement, and various agricultural uses. This paper aims to provide a comprehensive review of *Paulownia tomentosa* by exploring recent studies and findings related to its botanical characteristics, environmental and economic benefits, agricultural uses, and the challenges associated with its cultivation and spread. Recent studies have explored the potential of Paulownia tomentosa for soil improvement and environmental sustainability. Bakalár et al. (2023) investigated its use in revitalizing agricultural brownfields, highlighting its fast growth and climate change mitigation potential. Mamirova et al. (2022) demonstrated P. tomentosa's ability to phytoremediate soils contaminated with organochlorine pesticides and toxic trace elements, showing promising results for certain compounds. Liu et al. (2021) found that long-term fertilization, particularly organic-inorganic compound fertilizer, significantly increased soil enzyme activity and microbial biomass in Paulownia plantations, suggesting improved soil fertility. However, Skwiercz et al. (2020) cautioned that Paulownia monocultures could affect soil properties and increase plant parasitic nematode populations. Paulownia trees have demonstrated significant potential for carbon dioxide sequestration, making them valuable in climate change mitigation efforts. Studies have shown that a single three-year-old Paulownia tree can absorb approximately 10 kg of CO2 annually (Kozakiewicz et al., 2020). This finding highlights the importance of incorporating Paulownia into reforestation and afforestation efforts. Paulownia species are fast-growing, multipurpose trees with diverse applications in agroforestry and animal nutrition. The leaves of Paulownia trees have been recognized as a potential fodder source for livestock due to their nutritional value (Bodnár, 2020; Stewart et al., 2018). This review aims to assess the potential of Paulownia tomentosa for its growth potential in Libyan conditions, soil improvement, economic benefits, and the challenges associated with its cultivation in Libya

1. Botanical Classification and Geographic Distribution

1.1. Botanical Classification

Paulownia tomentosa belongs to the Paulowniaceae family, is a deciduous tree with large leaves (15–30 cm long and 10–20 cm wide), arranged in opposite pairs. The inflorescence is a large (15–30 cm long), erect panicle with 5–6 cm long, pale violet gullet-blossoms). The thick, somewhat fleshy synsepalous calyx is densely covered with brown indumentum. The calyx lobes are as long as the calyx tube. In the zygomorphic flowers, the adaxial bilobed lip of the corolla is slightly shorter than consisting of several species known for their rapid growth and high-quality timber. The botanical classification is as follows: Kingdom: Plantae, Phylum: Angiosperms, Class: Eudicots, Order: Lamiales, Family: Paulowniaceae, Genus: Paulownia, Species: *Paulownia tomentosa* (Erbar & Gülden, 2011).

1.2. Geographic Distribution

Originally found in central and western China, *Paulownia tomentosa* has been introduced to various regions worldwide, including Ukraine, and parts of Asia. Its ability to thrive in diverse climatic conditions and soil types has facilitated its widespread adoption (Ivaniuk *et al*., 2023).

2. Botanical Characteristics

2.1. Structure and Growth

Paulownia tomentosa is known for its impressive growth rate, reaching heights of 10 to 25 meters within a few years. The tree features large, heart-shaped leaves, which can grow up to 40 cm in length, and produces showy, fragrant flowers that are violet or blue and bloom in spring. The tree's rapid growth and attractive appearance make it a popular choice for ornamental planting and reforestation projects (Smith & Jones, 2023).

2.2. Root System

The extensive root system of *Paulownia tomentosa* (Figure 1) plays a crucial role in its ability to stabilize soil and access deep water sources. The roots can penetrate several meters into the soil, enhancing the tree's drought tolerance and making it suitable for arid regions (Buzan *et al*., 2018).

Figure (1) *Paulownia tomentosa* trees (https://www.contextoganadero.com)

3. Environmental Benefits

3.1. Carbon Sequestration

Paulownia tomentosa is highly efficient at sequestering carbon dioxide, a critical factor in mitigating climate change. A mature Paulownia tree can absorb up to 22 kilograms of CO_2 per day, significantly higher than many other tree species. This ability makes it an essential component in efforts to reduce atmospheric carbon levels (Marana ,2018; Ghazzawy *et al*., 2024).

3.2. Soil Improvement

Research on Paulownia trees demonstrates their potential for soil improvement and sustainable plantation management. Long-term fertilization experiments in Paulownia plantations showed that organic-inorganic compound fertilizers significantly increased soil enzyme activity, microbial biomass, and carbon source utilization (Liu et al., 2021). Paulownia fortunei growth on trace element contaminated soils amended with organic composts improved soil quality by increasing pH in acidic soils, enhancing organic matter content, and promoting soil biochemical quality (Madejón et al., 2014). Similar benefits were observed in a three-year study of fast-growing trees, including Paulownia, where compost additions improved soil fertility, especially in acidic soils, and increased biomass production (Madejón et al., 2016). Additionally, research on royal paulownia seedlings revealed that novel site preparation techniques, such as trenching and subsoiling, enhanced foliar nutrient levels, particularly nitrogen and phosphorus, which correlated positively with soil fertility levels (Johnson et al., 2002).

4. Economic Benefits

4.1. Timber Production

The timber produced by Paulownia tomentosa is known for being lightweight, strong, and resistant to warping, which makes it highly suitable for applications such as furniture, construction, and musical instruments (Pasiecznik, 2022). Its wood has low density, ranging from 0.272 to 0.317 g/cm³, and exhibits excellent dimensional stability with volumetric shrinkage and swelling of 7.78% and 8.41%, respectively (Akyildiz & Kol, 2010) . Recent studies on Paulownia tomentosa x elongata hybrids from European plantations confirm its potential for lightweight applications and as a substitute for expensive tropical species like Balsa (Barbu et al., 2022).

Most species of Paulownia exhibit extremely rapid growth and they can be harvested within 10-15 years, producing approximately 0.4 cubic meters of timber after 10 years (Pasiecznik, 2022). Under natural conditions a 10 year old Paulownia tree measures 30 - 40 cm diameter at breast height (dbh), and contains a timber volume of 0.3 - 0.5 m3 . Paulownia timber is lightweight, yet strong, dries rather rapidly and has an aesthetically pleasing light colored grain that does not warp, crack, or deform easily. In addition, the wood is easily worked, suitable for carving and has excellent insulation properties (Rao – 1986).

Each Paulownia tree is capable of producing approximately 1 cubic meter of wood by the age of 5 to 7 years. Recent studies suggest that the annual timber yield of Paulownia can range from 250 to 350 tons per hectare. More conservative estimates indicate a production of around 150 to 200 tons per hectare, depending on agricultural practices and conditions (Berdón et al., 2017; Humentyk & Bordus, 2023).

4.2. Honey Production

Paulownia trees present significant potential as a resource for honey production and pollination services, which are particularly vital given the current global challenges faced by pollinator populations. The decline in honeybee numbers is largely attributed to habitat loss, limited forage availability in monoculture farming systems, and the extensive use of pesticides. This reduction has led to a critical shortage in pollination services necessary for maintaining crop productivity and ecosystem stability (Breeze et al., 2014; Aizen and Harder, 2009).

One of the remarkable features of Paulownia trees is their ability to produce highly fragrant flowers on terminal branches before leaf emergence. These blossoms are not only attractive to honeybees but are also utilized in industries such as royal jelly production in China. Such characteristics make Paulownia a valuable species for enhancing pollination while supporting the health and sustainability of bee populations (Jensen, 2016).

Paulownia honey is often described as comparable to acacia honey in terms of quality and flavor, both of which are recognized for their light and aromatic profiles. Estimates for honey production per hectare vary: Bikfalvi (2014) reports yields of approximately 700 kg, while Paulownia Europa (2012) suggests higher potential, ranging between 1200 and 1500 kg per hectare. These variations indicate that factors such as environmental conditions, beekeeping practices, and colony health may influence honey yield.

Although detailed research on Paulownia honey yields remains limited, the tree is widely acknowledged in China as a prime source of nectar. For instance, Barton et al. (2007) note that a single hive can produce between 10 and 15 kg of honey during the flowering season. These insights underscore the species' potential to significantly contribute to honey production, particularly in agroforestry systems where it could integrate ecological and economic benefits.
By addressing key issues such as pollinator decline and providing a high-quality, marketable product, Paulownia demonstrates its versatility and promise as an agroforestry species with substantial environmental and economic value.

5. Agricultural Benefits

5.1. Animal Feed

Recent studies have highlighted the potential of *Paulownia tomentosa* as a valuable resource in animal nutrition. This fast-growing tree species is known for its high protein content, which can significantly enhance the nutritional value of livestock feed (Alagawany et al., 2020; Al-Sagheer et al., 2019). The leaves are rich in nutrients comparable to alfalfa hay, with higher contents of certain amino acids and minerals (Al-Sagheer et al., 2019). Paulownia flowers contain various phytochemicals, including flavonoids and phenylpropanoids, which exhibit antioxidant, anti-inflammatory, and immunoregulatory properties (Guo et al., 2023). Studies have shown that incorporating Paulownia leaf meal up to 15% in rabbit diets can improve feed conversion ratios and reduce cecal pathogenic bacteria without negatively affecting performance or blood constituents (Al-Sagheer et al., 2019). Analysis of Paulownia elongata leaves revealed crude protein content ranging from 14% to 23%, indicating their suitability as animal feed (Stewart et al., 2018). The versatility of Paulownia extends beyond animal nutrition, with applications in biomass production, wood manufacturing, soil erosion prevention, and phytoremediation (Costea et al., 2021). Additionally, Paulownia wastes have been explored as unconventional feedstuffs to address the rising costs of animal feed (Alagawany et al., 2020). The use of Paulownia in animal nutrition not only provides a sustainable feed source but also contributes to environmental quality by utilizing plant wastes effectively (Alagawany et al., 2020).. Protein and Organic matter (Table 1).

Table 1. Chemical compound of the Paulownia leaf (El-Showk et al., 2003)

Compounds	**In %**
Metabolisation energy	15 – 18 MJ/kg
Organic matter	91,4
Proteins	22,6
N	2,8 – 3,0
K	0,4
P	0,6
Ca	2,1
Fe	0,6
Zn	0,9

5.2. Sustainable Agriculture

Paulownia tomentosa plays a vital role in sustainable agriculture due to its ability to improve soil health and provide renewable resources. Intercropping Paulownia with crops offers multiple benefits for sustainable agriculture. It can improve microclimate conditions, reducing wind speed and increasing humidity, which may enhance crop yields (Jiang et al., 1994). While Paulownia can intercept sunlight, potentially affecting crops negatively, the system can still increase overall crop quality, output, and economic benefits (Wan, 2003). Various intercropping types exist, including timber-oriented and scattered tree approaches, with Paulownia contributing significantly to total net profits (Jiang et al., 1994). Overall, intercropping systems promote food security, environmental health, and agricultural resilience (Fung et al., 2019; Glaze-Corcoran et al., 2020).

6. Diseases and Pests

Paulownia tomentosa is susceptible to various diseases and pests that can affect its health and productivity.Common issues include root and collar rot caused by *Phytophthora* species (Aloi et al., 2021), damping-off, leaf spotting, and blight caused by various fungi (Mehrotra, 1997). Bacterial infections, such as those caused by *Erwinia carotovora* and *Pseudomonas aeruginosa*, can also be problematic (Hussien, 2020). Additionally, Paulownia witches' broom disease, caused by *phytoplasma*, poses a significant threat (Du et al., 2005). Research efforts are focused on developing disease-resistant varieties and improving management practices. Strategies include cultural practices like mound planting and soil amendments (Mehrotra, 1997), as well as genetic engineering approaches. Transgenic *Paulownia* expressing antimicrobial genes, such as thionin (Hussien, 2020) and shiva-1 (Du et al., 2005), have shown increased resistance to bacterial and *phytoplasma* infections, respectively, offering promising avenues for disease control. These advancements offer promising pathways for disease control and underscore the importance of continued research to ensure the tree’s viability and productivity.

Conclusion

In summary, *Paulownia tomentosa* represents a transformative opportunity for both environmental restoration and economic development. This rapid-growing, resilient tree offers unparalleled benefits, including soil improvement, enhanced water retention, and a significant capacity for carbon sequestration—making it a vital tool in combating climate change. Its lightweight, durable timber is highly valuable for commercial applications such as furniture and construction, while its protein-rich leaves provide an excellent feed resource for livestock.

For Libya, the strategic cultivation of *Paulownia tomentosa* can be a game-changer. It offers a sustainable solution to combat desertification, restore degraded lands, and enhance agricultural productivity. Its ability to improve soil health, reduce dependency on chemical fertilizers, and support reforestation efforts aligns perfectly with the country’s goals for environmental sustainability and resilience against climate challenges.

Moreover, the tree’s timber is not only fast renewable but also of high quality—resistant to warping and suitable for various industries, ensuring economic profitability. The vibrant flowers serve as a crucial nectar source for honeybees, boosting honey production and diversifying farmers’ income streams through integrated agroforestry and apiculture.

Embracing *Paulownia tomentosa* in Libya’s agricultural landscape promises a sustainable pathway toward ecological restoration, increased productivity, and economic growth. Its multifaceted benefits make it an indispensable resource for building a resilient, environmentally friendly, and prosperous future.

Recommendations

1- Conduct field trials and Pilot Projects to implement small-scale experimental plantations in various regions of Libya to assess the adaptability of *Paulownia tomentosa* under local conditions, and to identify optimal cultivation and management practices.
2- Develop training and awareness programs by provide training workshops for farmers on sustainable planting, care, and utilization of Paulownia, emphasizing its environmental and economic benefits.
3- Create policies that incentivize Paulownia cultivation, including financial grants, easy access to quality saplings, and technical support to encourage widespread adoption.
4- Utilize Paulownia in afforestation efforts, especially in desertified and degraded areas, to improve soil health, combat desertification, and increase green cover.
5- Establish marketing channels for timber, honey, and other derived for Paulownia products to ensure economic sustainability and profitability for local farmers.

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