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Review article

Considerations for the selection of *Gmelina arborea* Roxb. *ex* Sm. seeds: a review

Consideraciones para la selección de semilla de *Gmelina arborea* Roxb. *ex* Sm.: una revisión

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Abstract

Gmelina arborea is a tropical species of high commercial value for forest plantations due to its rapid growth and its various uses. Typically, its timber yield ranges from 15 to 21 m^3 ha^{-1} $year^{-1}$ and from 40 to 50 m^3 ha^{-1} $year^{-1}$ in optimal sites. However, seed availability, dormancy, and low viability limit large-scale seedling production. This paper compiles key considerations for seed selection and management, from harvest through seedling establishment. It is important to harvest yellowish-brown fruits (at peak embryonic maturity), remove the pulp, and dry the seeds in the sun for 7 days to prevent damage from pests and diseases during transport and storage. Dormancy can be broken by pre-germination treatments with gibberellic acid (GA_3; 200 ppm, 24 h), concentrated sulfuric acid (H_2SO_4; 10 min), or cold water (24 h), resulting in germination rates of up to 98.88, 93.33, and 80 %, respectively. Size is an important factor in germination: large seeds (0.94 g) achieve an 80.25 % germination rate and a faster germination rate. To maintain viability, a humidity level of 5-8 % and a temperature of 7-8 °C are recommended, along with hydration-dehydration treatments or the use of oxygen microbubbles to extend the shelf life of the germplasm. Finally, given the species' high genetic diversity (95.4 % polymorphism), it is recommended to collect seeds from different sources to ensure their adaptation and resilience to climate change.

Keywords: Seed storage, harvest, dormancy, germination, longevity, seedling.

Resumen

Gmelina arborea es una especie tropical de alto valor comercial para plantaciones forestales por su rápido crecimiento y por los diversos usos que tiene; normalmente, su producción de madera es de 15 a 21 m^3 ha^{-1} año^{-1} y de 40 a 50 m^3 ha^{-1} año^{-1} en sitios óptimos. Sin embargo, la disponibilidad de semilla, los problemas de dormancia y de baja viabilidad son factores que limitan la producción de plántulas a gran escala. Este trabajo compila aspectos básicos para considerar en la selección y manejo de semilla, desde la cosecha hasta el establecimiento de plántulas. Se destaca la importancia de recolectar frutos marrón-amarillentos (máxima madurez embrionaria), remover la pulpa y secar las semillas al sol por 7 días, para evitar daños por plagas y enfermedades durante el transporte y almacenamiento. La dormancia se puede romper mediante tratamientos pregerminativos con ácido giberélico (GA_3; 200 ppm, 24 h), ácido sulfúrico concentrado (H_2SO_4; 10 min), agua fría (24 h), para obtener germinaciones de hasta 98.88, 93.33 y 80 %, respectivamente. El tamaño es una característica de importancia para la germinación: semillas grandes (0.94 g) alcanzan 80.25 % y mayor velocidad de germinación. Para conservar la viabilidad, se recomienda de 5 a 8 % de humedad y de 7 a 8 °C junto con tratamientos de hidratación-deshidratación o uso de microburbujas de oxígeno para ampliar la vida útil del germoplasma. Finalmente, debido a la alta diversidad genética (polimorfismo de 95.4 %) que tiene la especie, se sugiere recolectar semilla de diferentes procedencias para garantizar su adaptación y resiliencia al cambio climático.

Palabras clave: Almacenamiento de semilla, cosecha, dormancia, germinación, longevidad, plántula.

Introduction

Gmelina arborea Roxb. *ex* Sm. is native to India, Bangladesh, Sri Lanka, Myanmar, Thailand, Southern China, Laos, Cambodia, Pakistan, Vietnam, Nepal and Sumatra in Indonesia (Wee et al., 2012). Its wood is among the finest in the tropics and has a wide range of uses: particleboard, plywood, lumber for construction, furniture, general carpentry, packaging, musical instruments, pulp for paper, firewood, and charcoal (Patil et al., 2018). In addition to its timber uses, some people have used its fruit as livestock feed, while various groups value its roots, fruit, leaves, flowers, and bark for their medicinal properties (Onwe et al., 2023).

Foresters have used this species in forest plantations because of its rapid growth and straight trunk, which allows it to produce timber volumes of 15 to 21 m^3 ha^{-1} año^{-1} in sites where it thrives and 40 to 50 m^3 ha^{-1} año^{-1} in areas with the soil and rainfall conditions required by the species (Dvorak, 2004). This characteristic has led several tropical countries (*e. g.*, Colombia, Costa Rica, Venezuela, Brazil, *Honduras*, Ivory Coast, Panama, and others) to incorporate it into their plantation programs (Ramírez-Jaramillo et al., 2019). Likewise, Dvorak (2004) estimated that, by 2020, approximately 800 000 hectares had been planted in the world's tropical and subtropical regions, given the species' high potential and utility. In 2014, Mexico contributed 24 061 hectares of plantations (Secretaría de Medio Ambiente y Recursos Naturales [Semarnat], 2014).

Gmelina arborea can be easily propagated, but the availability of seeds to produce sufficient quantities of seedlings for large-scale planting is a major constraint (Siregar et al., 2020). In this regard, growers and researchers need to understand the key factors involved in seed selection and be aware of dormancy and low viability issues affecting this species (Rotowa & Adeagbo, 2019). Failing to address the above could result in an inability to fully realize the timber potential of *G. arborea* in commercial forest plantations due to insufficient quantity and quality of germplasm. Within this context, the objective of this review was to identify the key factors that should be considered when selecting *G. arborea* seeds, both prior to and during germination.

To this end, the authors conducted a systematic review of research articles published between 1980 and 2025 on the topic of interest, as available in bibliographic databases (Scopus, Web of Science) and metasearch engines (Google Scholar); the keywords used were *Gmelina arborea*, seed, *semilla* and *semente*. Each abstract was reviewed to ensure the article was relevant to the topic prior to selection; the documents were chosen for their content after a full reading. The articles were summarized in a matrix containing titles, study objectives, materials and methods, results, conclusions, gaps, and limitations; the documents were grouped and discussed based on the identified subtopics (Handayani et al., 2025).

Development and Discussion

Characteristics of the seeds

The key aspects of *G. arborea* seeds to be considered before and during germination fall into eight general categories: (1) Seed production and harvest, (2) Post-harvest extraction, (3) Morphology and Physiological quality, (4) Germination and dormancy, (5) Longevity-storage, (6) Physiological quality-vigor, (7) Genetic influence-provenance, (8) Early seedling growth.

Seed production and harvesting

The fruits of *G. arborea* are the structures in which the seeds are produced. The amount harvested varies from year to year, as it depends on the (good or poor) quality of the trees' flowering (Khanduri et al., 2019). Therefore, it is important to recognize that the amount of seeds to be harvested varies over time (year, season). Open pollination in natural populations of this species is insufficient; therefore, it is recommended to manually pollinate the flowers from February through April (Hasnat et al., 2016), especially in seed orchards, in order to increase the fruit yield by up to 23 % (Khanduri et al., 2019). For this purpose, it is necessary to have a phenological calendar for the species to enable identification of the optimal time for fruiting and scheduling of seed collection activities.

The fruiting and seed-harvesting seasons occur from April to May and from May to July, respectively (Hasnat et al., 2016). These should be taken into account when planning harvesting and processing activities. However, the ripening period can vary from year to year due to changes in the weather (Saralch & Singh, 2013). It is necessary to assess the ripeness of the fruit to ensure maximum yield. In this regard, it is preferable to harvest the fruits from the tree canopy rather than from the ground. In the former case, a yellowish-brown color indicates that the seeds have reached maximum embryo maturity (*i. e.*, that they are fully developed and differentiated) (Patil et al., 2018), have sufficient energy (reserves) to germinate vigorously, and contain low levels of germination inhibitors (Anandalakshmi et al., 2016).

Harvesting and post-harvest handling

Extraction involves obtaining seeds from the fruits. Although there are some variations in the method used, it is recommended to obtain the germplasm from dry fruits or after fermenting them for two weeks; in both cases, higher germination rates are guaranteed (Ogunnika & Kadeba, 1993). To make it easier to extract the seeds by hand, the fruits are crushed in mortars, beaten with sticks while in sacks or tarps, or rubbed on the ground or against a half-inch metal mesh. Alternatively, this process can be carried out mechanically using seed crushers, pulping machines, or hammer mills (Adeleye et al., 2021; Florido & Cornejo, 2002). Mechanized seed extraction methods require purchasing machinery, which is not always feasible; however, one can opt for local manufacture of site-specific machinery to avoid relying on imports.

Because the fruit pulp decomposes quickly, it is important to remove it completely from the seeds after harvest; otherwise, the residue attracts insects and fungi that could infest the seeds during transport or storage. For this reason, it is important to prevent fermentation, as it can damage the seeds (Adeleye et al., 2021). The seeds are washed and dried in direct sunlight for 7 days (Florido & Cornejo, 2002).

Morphology and physical quality

The dimensions of the *G. arborea* seeds are: major diameter, 18.16 mm; intermediate diameter, 10.52 mm; minor diameter, 9.40 mm; and 66.91 % sphericity (Onwe et al., 2023). Their bulk density is 0.64 kg m^{-3} and their true density is 0.96 kg m^{-3} (Onwe et al., 2023). The weight of 1 000 seeds is 621.33 g, and their moisture content ranges from 30 to 51 % (Onwe et al., 2023). The coefficient of friction, evaluated for different materials (wood, aluminum, steel, and glass) used in the design of equipment for the transport, handling, and processing of seeds, is highest for wood (0.40) and lowest for aluminum (0.34), but intermediate for galvanized steel and glass (0.37 and 0.36, respectively); and the angle of repose is 24.09° (Onwe et al., 2023). The breaking force of the seed on the horizontal axis is 0.808 kN (Onwe et al., 2023). The properties of *G. arborea* seeds are essential for the design and development of equipment used for their transport, handling, and processing, such as sorters, graders, and cracking machines (Onwe et al., 2023).

Germination and dormancy

When the seeds of this species are obtained from dried fruits or fermented for 2 weeks, germination rates of 90 and 86 %, respectively, are achieved (Ogunnika & Kadeba, 1993). After the seeds have been soaked in water for 48 hours, and if they come from fruits that are yellowish-brown in color, a cumulative germination rate of 77 % is achieved within 30 days (Adebisi et al., 2011) and up to 84.66 % when planted outdoors under shade cloth (Patil et al., 2018). However, by soaking the seeds in gibberellic acid (GA_3) at a concentration of 200 ppm during 24 hours, germination rates of 98.88 % can be achieved; with concentrated sulfuric acid (H_2SO_4) for 10 minutes, a rate of 93.33 % is obtained, and 80 % with cold water during 24 hours (Berry et al., 2021). Higher germination is achieved with a growing medium mixture of soil, sand, and vermicompost (2:1:1) compared with coconut coir or white sand (Maharana et al., 2018).

These treatments improve germination rates and reduce germination time, demonstrating that seed dormancy can be broken. The application of pre-germination treatments increases the germination rate; therefore, their use is recommended. For example, soaking the seeds in water and agitating them for 24 hours helps leach out growth inhibitors (Rotowa & Adeagbo, 2019).

Dormancy in this species varies and may be more pronounced in some genotypes than in others once they reach physiological maturity (Alizaga & Herrera, 2001). One example is its average germination period (the number of days from sowing until half of the total number of seeds have germinated); this is 25 days for *G. arborea* (Blakesley et al., 2002), which makes it a fast-germinating plant.

The size (weight, g) of the seeds affects the germination rate of the species. Large seeds (0.94 g) attain 80.25 %; medium seeds (0.57 g), 56.50 %, and small seeds (0.38 g), 35.50 % (Owoh et al., 2011); likewise, large seeds also exhibit a higher germination rate (0.986 germinated seeds day^{-1}) (Galán-Larrea et al., 2000). Seed size is a key factor in predicting the germination of *G. arborea*; therefore, given their rapid germination, the use of large seeds is recommended in this case (Fornah et al., 2017).

However, when size is based on the dimensions of the seeds (length and width), the difference between large and small seeds in terms of germination rate is not significant. It is significant, however, in terms of germination speed: small seeds germinate faster than large ones (Agboola, 1996). This may be an adaptive mechanism designed to maximize the probability of establishment under extreme conditions (Tomar et al., 2024), as it allows the species to achieve a high germination rate regardless of seed size.

On the other hand, the germination rate of the species through direct sowing of coated seeds reached its highest level (17.7 %) in 26 days when the seed material (seed bombs) was coated with a mixture of clay, sawdust, bone meal, and vermicompost (3:3:1:1) (Zubaidah et al., 2022). It is assumed that this low percentage is due to the lack of seed selection based on a viability analysis prior to coating.

Another technique that has been tested for direct seeding of this species is the use of briquettes (a mixture of materials such as seeds, soil, compost, lime and other organic materials) for field germination. In a nursery setting, germination rates of up to 78.5 % have been achieved within 60 days using briquettes composed of 10 % soil, 45 % compost, 35 % rice husk charcoal, 5 % lime, and 5 % tapioca (Sudrajat & Rustam, 2020). At planting, the field trials yielded a survival rate of 56.8 %, with 120.32 cm and 15.92 mm of growth in height and diameter, respectively, in 12-month-old seedlings (Sudrajat & Rustam, 2020). This approach can be applied to degraded lands and forests to achieve large-scale reforestation efforts that will prove more successful and cost-effective, requiring less labor.

According to tests conducted to evaluate the effect of the growing medium and light intensity used for the germination of *G. arborea*, a germination rate of up to 80 % can be obtained when the seeds are sown in a mixture of soil, sand and manure (1:1:2) under a light intensity of around 50 % (Kumari et al., 2025). Under these conditions, seedling vigor can be improved, thereby promoting the success of reforestation efforts, agroforestry systems, and commercial plantations.

Longevity and storage

In general, seeds are stored after their initial quality has been assessed, as this provides information about the characteristics of the batch. Seeds should only be stored in batches where the initial germination rate was above 50 %, since a lower rate indicates that the seeds are damaged (Yulianti et al., 2020). Because *G. arborea* seeds are suborthodox, they can be stored for only one year without a significant reduction in viability (Yulianti et al., 2020). To this end, it is recommended that they have a moisture content of 5 to 8 % and be kept at a temperature of 7 to 8 °C (Florido & Cornejo, 2002); however, it is also recommended to keep them at 18 to 20 °C and at a relative humidity of 50 to 60 % (Yuniarti et al., 2018).

However, seeds from certain sources are classified as hardy because they can withstand drying to moisture levels as low as 3 % without adversely affecting viability and germination parameters (Correa et al., 2013; Waiboonya et al., 2019). For example: seeds dried to a 3.9 % moisture content and stored at temperatures ranging from -20 to 0 °C for 270 days showed germination rates of 77 to 95 % (Naithani et al., 2004). When the opposite occurs, it is probably because the water that helps maintain cellular structures is being removed (Dasgupta et al., 1982).

For storage, jute or cotton sacks, or thin plastic bags (0.1 to 0.25 mm thick) that allow oxygen exchange, can be utilized (Yulianti et al., 2020). It is essential to control diseases, insects, and fungi, since seeds are stored at temperatures and humidity levels that promote their growth and development. The spread of disease can be prevented by fumigating with CO_2, briefly immersing the seeds in cold or hot water, treating them with fungicide solutions, or using a dry treatment (Yulianti et al., 2020).

The shelf life of *G. arborea* seeds during storage is extended through hydration and dehydration treatments, as these activate the self-repair mechanism during the hydration phase (Cremaldi & Bhushan, 2018). In addition, the use of oxygen microbubbles is a technology that helps revitalize and improve the germination rate of seeds that have been stored for a year by up to 80 % (Siregar et al., 2020). The treatments described have practical applications for improving the production of seedlings intended for the establishment of forest plantations, community forestry, and ecosystem restoration programs.

Physiological quality and vigor

Gmelina arborea is characterized by intermediate germination; that is, it has limited tolerance to drying, cold and storage periods of less than one year; it is also synchronous: viable seeds germinate within a relatively short period and in close succession (Blakesley et al., 2002). Seeds from its yellowish-brown and brown fruits treated with organic powders of African basil, red chili, or black pepper (proven vigorization treatments that maintain seed quality during storage, 10 g of product per 100 g of seed), stored for 60 and 120 days (at an average temperature of 29 °C and 75 % relative humidity) exhibit greater potential for growth and rapid seedling development (Adebisi & Bello, 2015). These qualities are ideal for efficient nursery production, as they minimize the need for germination areas, where seeds are vulnerable to pests and diseases.

Genetic influence and provenance

There is no significant genetic variation in seed morphology between populations or within them (Naik et al., 2009). However, analysis of genetic diversity using molecular markers reveals a high degree of polymorphism (95.4 %) (Naik et al., 2009; Wee et al., 2012). This characteristic is of paramount importance in *G. arborea*, as it promotes greater resistance and tolerance to pests, diseases, and climate change. It also makes it possible to establish plantations under various site conditions, optimize material production through clonal selection, and develop breeding and genetic conservation programs (Naik et al., 2009).

The origin of the germplasm has a significant influence on biomass variables when it comes from different regions. In particular, differences were observed in the dry weight of the aboveground biomass (7.80 g) and total biomass (12.89 g) in 10-week-old seedlings (Fornah et al., 2017).

Furthermore, Hernández-Castro et al. (2021) estimated that significant genetic gains of 6.11 % in diameter and 9.36 % in commercial volume can be achieved in plantations at 34 months of age; Chacón and Murillo (2005) proposed selecting young plants based on their vigor and apical dominance for use as planting stock in commercial forest plantations.

In order to preserve maximum genetic diversity, the germplasm used in plantations must come from multiple natural populations and different locations. This contributes to the success of establishing plantations, as it promotes better initial growth and enables faster production of pulp, timber and firewood.

Early seedling growth

In general, the large seeds (0.94 g) of *G. arborea* produce taller seedlings at 3 months old (11.42 cm) compared to the medium (0.57 g) and small (0.38 g) seeds, which measure 8.84 and 8.76 cm, respectively (Owoh et al., 2011). On average, they produce a greater number of leaves (10.36), and their collar diameter (0.18 cm) and leaf area (15.40 cm^2) are larger, with higher dry weights for the stem (4.36 g) and root (1.15 g) than medium and small seeds (Agboola, 1996; Owoh et al., 2011). The seedlings also exhibited higher relative growth rates (0.69 g m^{-1}) and average growth rates (2.66 g m^{-1}). The origin of the seed also affects seedling size; for example, at 4 months of age, average heights of 33.22 to 34.75 cm, stem diameters of 2.01 to 2.39 cm, and numbers of leaves ranging from 16.53 to 19.56 have been recorded (Rotowa & Adeagbo, 2019).

The site where the seedlings are established affects their growth. In this regard, the performance of the species differs between a deforested site (with a slight degree of degradation) and an undisturbed site. A comparison of the two sites at 15 months of age showed lower average growth in height and diameter at the deforested site (80.90 and 0.85 cm, respectively) than at the undisturbed site (89.90 and 1.04 cm, respectively) (Hossain, 2012).

The substrates and growing conditions also affect the results. Kumari et al. (2025) observed that 8-month-old seedlings of *G. arborea* reached greater height, stem diameter, and number of leaves (95.31 cm, 12.88 cm, and 7.96, respectively) when grown in a mixture of soil, sand and manure (2:1:2) and under a light intensity of approximately 50 %. Areas experiencing moderate to severe drought are not recommended for establishing this species, as it is not tolerant of such conditions (Sachan et al., 2020).

Therefore, foresters and growers are advised to use large seeds from sources with higher potential, sown in the best growing medium and under optimal light conditions, to profit from the seedlings' superior early growth. Furthermore, given *G. arborea*'s growth performance, it can be utilized to restore areas with mild degradation.

Conclusions

Harvesters should pick yellowish-brown fruits to ensure maximum seed maturity and obtain seeds with sufficient germination potential. In addition, the pulp must be completely removed from the fruit, and the seeds must be dried in the sun for 7 days after harvesting.

Seeds should be selected based on size, because larger seeds have a higher germination rate and speed, and produce taller, more vigorous seedlings. Dormancy can be inhibited primarily by immersion in gibberellic or sulfuric acid. During storage, the moisture content of the seed must be maintained between 5 and 8 %, and the seed must be stored at temperatures of 7 to 8 °C. It is recommended to apply hydration-dehydration treatments or oxygen microbubbles. Managers should use germplasm from different populations and locations to maximize genetic diversity and ensure resistance or tolerance to pests, diseases, and the adverse effects of climate change.

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Conflict of interest

The authors declare that they have no conflicts of interest and state that they have no ties to institutions sponsoring the research, nor do they derive any professional, employment-related or financial benefits.

Contributions by author

Andrés Flores: conceptualization of the idea, development of the methodology, analysis of the data, and drafting of the first manuscript; Jorge Méndez González: critical review and substantial feedback on the manuscript; Tomás Pineda Ojeda: revision and substantive editing of the final manuscript; Eulogio Flores Ayala: drafting and discussion of the document; Enrique Buendía Rodríguez: supervision of the work and creation of the database. All authors have read the document and agree to its publication.

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