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Comparative study of different pre-sowing treatments on seed germination of *Acacia mangium*

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Abstract

Acacia mangium is a fast-growing, nitrogen-fixing tropical tree species widely cultivated in forestry, agroforestry, and land restoration programs due to its ability to improve soil fertility, enhance nutrient cycling, and contribute to carbon sequestration. Seed germination and seedling growth are influenced by the age of the seed. However, seed dormancy caused by a hard and impermeable seed coat remains a major constraint to its germination and establishment. This review synthesizes existing literature on seed dormancy, seed characteristics, and pre-sowing treatment methods used to improve germination in *Acacia mangium* and related species. The review highlights different types of seed dormancy, including physical, physiological, and morphological dormancy, and discusses their underlying mechanisms. Various pre-sowing treatments such as hot water treatment, acid scarification, mechanical scarification, smoke treatment, and application of gibberellic acid (GA₃) are critically analyzed based on their mode of action, effectiveness, advantages, and limitations. In addition, key factors affecting treatment efficiency such as seed coat thickness, treatment duration, temperature, chemical concentration, seed maturity, moisture content, and storage conditions are examined.

A comparative analysis of physical, chemical, and thermal treatments indicates that scarification methods are generally more effective in breaking physical dormancy, while hormonal treatments enhance germination and seedling vigor. The review also integrates findings from previous studies on growth performance, ecological benefits, and invasiveness of *Acacia mangium*, providing a balanced perspective on its utilization. Overall, this review provides a comprehensive understanding of seed dormancy and pre-sowing treatments in *Acacia mangium*, offering valuable insights for improving nursery practices, plantation success, and sustainable management while addressing potential ecological concerns.

Keywords: *Acacia mangium*, seed dormancy, pre-sowing treatment, scarification, germination, GA₃, seed physiology

Introduction

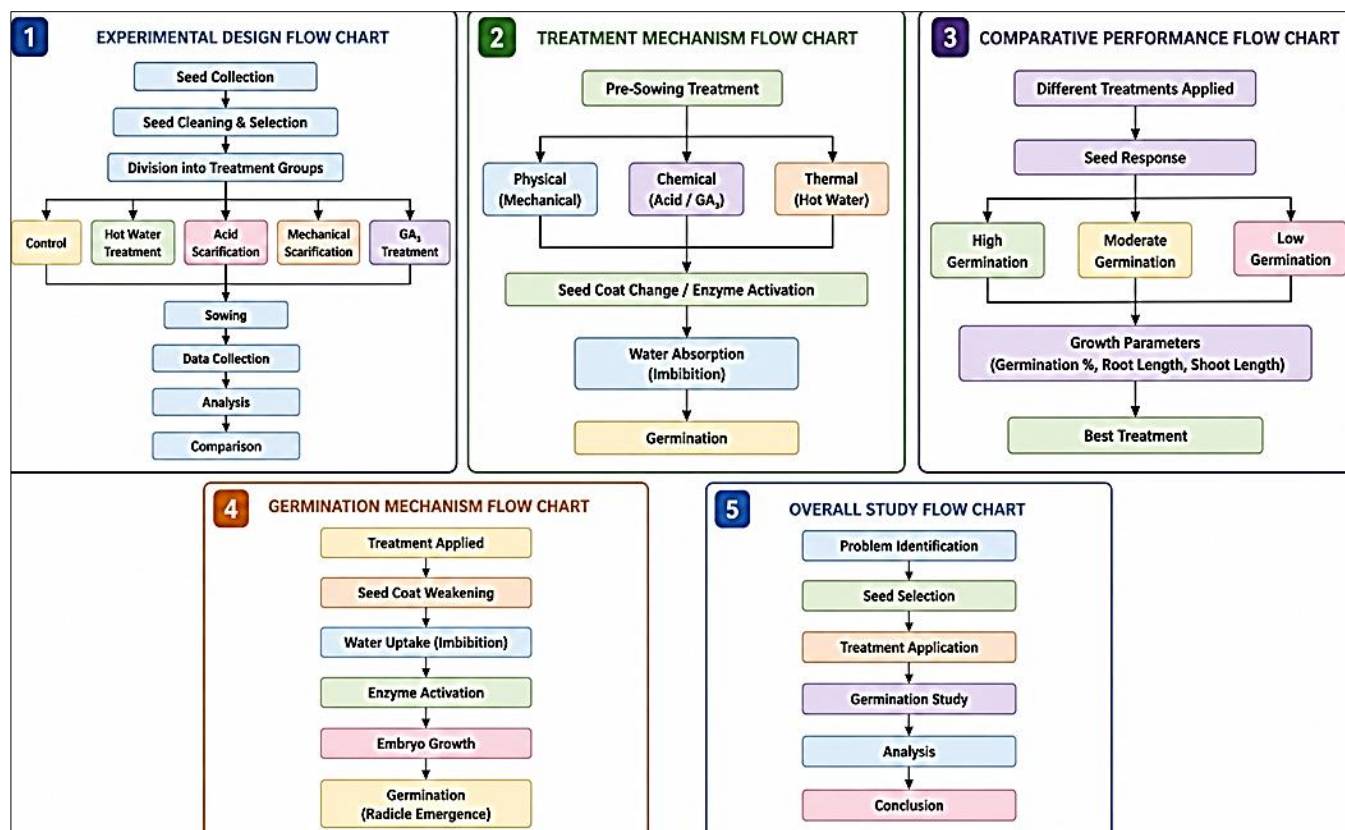
Tropical acacia from Australia are extensively cultivated globally, particularly in Asia where they were originally brought (Midgley and Turnbull 2003; Inagaki *et al.* 2011; Richardson *et al.* 2011), as well as in Africa (Bernhard-Reversat 1993; Tassin *et al.* 2012; Dubliez *et al.* 2018) and South America (Franco and de Faria, 1997; Chaer *et al.* 2011; Attias *et al.* 2013) [13, 21, 30, 55]. Seed germination and growth occur in mature seeds. Seed germination increased with an increasing collection period (Netam *et al.*, 2025). Nurseries provide the means to control moisture, light physical and chemical soil constituents in such a way as to produce healthy and uniform seedlings for planting. Several factors can influence seedling growth in the nursery (Nishad *et al.*, 2025) [49]. Agroforestry is a comprehensive term encompassing land-use systems where woody perennials like trees, shrubs, and bamboos are cultivated alongside herbaceous plants such as crops, pasture, and/or livestock. These elements are organized spatially or temporally, facilitating ecological and economic interactions between the tree and non-tree components. The principal constituents of agroforestry systems include trees, shrubs, crops, pastures, and livestock, along with factors like climate, soil, and the surrounding environment (Bargah *et al.*, 2024) [9]. These plants are utilized in agricultural practices, forestry, and agroforestry to enhance soil fertility (notably nitrogen levels), to capture carbon, and perhaps to rejuvenate nutrient cycles in distressed lands and woodlands. They are also valued for commercial wood production, decorative

uses, and for providing timber and charcoal (Bernhard-Reversat 1993; Franco *et al.* 1994; Parrotta and Knowles, 1999; Fuentes-Ramírez *et al.* 2011; Bouillet *et al.* 2013; Sitters *et al.* 2013; Permadi *et al.*, 2017) ^[13, 30]. Seedlings are small plants with enough potential to grow into mature trees. These seedlings grow naturally, but they can also be propagated by seeding and germinating, which helps them to sprout quicker and boost their chances of survival. The factors must be optimal to produce a health and vigorous seedlings, and among them, the genes and the nursery environment determine to a large degree how a tree can survive (Minj *et al.*, 2024). Plants are propagated and grown to a size that can be planted in a nursery. A quality nursery stock is necessary to create a good plantation. The necessity of forest nurseries in order to properly nurture seedlings before planting them on land that needs to be replanted (Verma *et al.*, 2024). Often, the growth of forests or crop production tends to improve in nitrogen-deficient areas when nitrogen-fixing species (NFS) like Australian Acacia are present (Binkley 1992; Khanna 1998; Bouillet *et al.* 2013; Nambiar and Harwood 2014; Paula *et al.* 2015; Dubliez *et al.* 2018), alongside an increase in soil nitrogen quality (Sanginga *et al.* 1986; Binkley 1992; Parrotta, 1999; Kaye *et al.* 2000; Resh *et al.* 2002; Ludwig *et al.* 2004; Hagos and Smit 2005; Sitters *et al.* 2013). Most Australian Acacia have the ability to capture carbon in both the soil and living organisms, contributing to efforts aimed at addressing climate change (Binkley 1992; Kaye *et al.* 2000; Resh *et al.* 2002; Lee *et al.* 2015; Forrester *et al.* 2013), although in some instances, they may not lead to an increase in soil carbon storage (Voigtlaender *et al.* 2012; Oelofse *et al.* 2016) ^[17, 18, 29, 40, 44, 45, 53, 54, 63].

Most of Australia's Acacia have characteristics connected to invasiveness. Twenty-three species have been identified as invasive so far; some are important invasive species in several geographic areas (Richardson and Rejmánek 2011; Gibson *et al.* 2011; Rejmánek and Richardson 2013; Richardson *et al.* 2015). Richardson *et al.* (2011) showed that all species that have been widely planted for forestry or other uses have become invasive when documenting the worldwide biogeography and invasion ecology of Australian Acacia. Many elements influence whether an exotic species turns invasive, including life-history features and the degree, level, and length of use of the species in the new surroundings. On Australian Acacia, a lot of study has been done in this regard. The degree of invasiveness for Acacia is explained by interactions between features, human use, and residence duration (Castro-Díez *et al.* 2011). Usually, there is a long delay between introduction and planting and the beginning of invasive spread; this results in a significant 'invasion debt' in many locations where the extensive planting of non-native species has recently taken place (Rouget *et al.* 2016) ^[20, 33, 55, 56, 57].

Among the Australian Acacia widely cultivated worldwide, *Acacia mangium* clearly offers advantages in agricultural, agroforestry, and forestry ecosystems (Bernhard-Reversat 1993; Franco *et al.* 1994; Parrotta and Knowles, 1999; Richardson *et al.* 2004; Kull *et al.* 2011; Epron *et al.* 2013). The ability of *Acacia mangium* to enhance soil fertility (Wang *et al.* 2010; Forrester *et al.* 2013; Koutika *et al.* 2014; Machado *et al.* 2017; Tchichelle *et al.* 2017), alter the soil faunal, microbial, and bacterial populations (Bernhard-Reversat 1993; Bini *et al.* 2012, 2013; Huang *et al.* 2014; Pereira *et al.* 2017), and stimulate the growth of crops or trees and forest output (Bouillet *et al.* 2013; Epron *et al.*

2013; Paula *et al.* 2015) are key factors contributing to its extensive cultivation in commercial monoculture plantations or mixed plantings with other tree species or crops in regions with poor soils. This species is seen as beneficial for these uses because of the increased nutrient cycling, higher nutrient availability, and microbial activities that result from its presence (Khanna 1998; Bini *et al.* 2012; Rachid *et al.* 2013; Santos *et al.*, 2017a, b). However, the introduction of *Acacia mangium* into agricultural, agroforestry, or vast open regions is progressively being demonstrated to set off significant biological invasions. The number of papers detailing the invasive spread of *Acacia mangium* from planting sites is growing quickly; the species is currently listed as an invading species in Asia, Indonesia, southern Africa, and South America (Richardson and Rejmánek 2011; Ismael and Metali 2014; Aguiar *et al.* 2014; Meira-Neto *et al.* 2018; Souza *et al.* 2018) ^[2]. Such invasions are lowering the general benefit from using the species and is generating conflicts of interest between (agro) foresters on the one hand and conservationists and natural resource managers on the other. Many temperate parts of the world where other Australian Acacia species (and other legume trees) have been grown outside their natural habitat are experiencing such conflicts. Many sectors are implementing management projects to lessen such conflicts (e.g. Kull and Rangan 2008; Dickie *et al.* 2014; van Wilgen and Richardson 2014; Shackleton *et al.* 2018 and references therein). Due to their great adaptability, Australian Acacia are particularly favored for planting; climatic modeling indicates that roughly a third of the earth's land areas are appropriate for their growth (Richardson *et al.* 2011). The biggest region of tropical Australian acacia plantations is found in Southeast Asia, where they span around 2 Mha (Midgley and Turnbull 2003; Arisman and Hardiyanto 2006; Kull and Rangan 2008) ^[3]. Native to areas of Indonesia, Papua New Guinea and Australia, *Acacia mangium* Willd. Is a huge tree that can grow up to 30 m tall. The species creates many flowers, mostly pollinated by bees (Midgley and Turnbull 2003). It thrives in coastal, tropical lowlands (below 300 m in altitude) and across a spectrum of forest types (from rainforests to open forests), as well as in woodlands impacted by fire (Midgley and Turnbull 2003). The natural range of *Acacia mangium* overlaps with the warm and hot tropical climate zones, where temperatures are consistently high throughout the year. The mean maximum temperature during the hottest month typically falls between 31 °C and 34 °C, and the mean minimum temperature during the coolest month ranges from 15 °C to 22 °C (Otsamoet *et al.* 1997; Midgley and Turnbull 2003). With summer (January to March) being the wettest season, the mean annual rainfall throughout its natural range is between 1500 and 3000 mm. This fast-growing species prefers well-drained soils of moderate to low fertility (Franco *et al.* 1994; Cole *et al.* 1996; Bouillet *et al.* 2013; Aguiar *et al.* 2014) ^[2]. But outside of their natural habitat, an extended dry season and sandy, nutrient-poor soils may cause growth during the first year (Koutika *et al.* 2018). Similar to many other acacia species, *Acacia mangium* may develop on soils with pH under 4 (Franco and de Faria, 1997; Midgley and Turnbull 2003) and is suited to acidic soils. The advantages and risks of *Acacia mangium* in places where it is grown are examined in this study. Native range not with standing, the article explores whether it is practical to encourage planting of the species in order to maximize its benefits and lower existing and possible future negative repercussions from invasiveness ^[13, 16, 18, 29, 30, 43, 53, 55, 56, 57, 61].



Source: Alok Singh Bargah

Fig 1: Flow Chart Illustrating Experimental Design, Treatment Mechanism, and Comparative Analysis of Pre-Sowing Treatments in *Acacia mangium*

2. Taxonomy

- **Botanical name:** *Acacia mangium*
- **Family:** Leguminosae
- **Subfamily:** Mimosoideae

Pedley Vernacular/common names: Common names in Indonesia: manggahutan, tongkehutan (Ceram), nak (Maluku), laj (Aru), jerri (Irian Jaya) (Turnbull 1986). Common names in other countries: black wattle, brown salwood, hickory wattle, mangium, sabahsalwood (Australia, England); mangium, kayu SAFODA (Malaysia); arr (Papua New Guinea); maber (Philippines); zamorano (Spain); kra thin tepa, krathin-thepha (Thailand).

3. Botanical Descriptions

3.1 Tree morphology

Acacia mangium is a kind of evergreen tree, up to 30 m tall. The bole can be unbranched for more than half of the total tree height. It is sometimes fluted at the base and the tree diameter rarely exceeds 50 cm. Bark is rough and furrowed, either grey or brown in color. Small branches are winged. It may be reduced to a small tree or large shrub of 7-10 m on unfavorable sites. The bark surface is rough, furrowed longitudinally, and varies in colour from pale grey-brown to brown. The lower bole is sometimes fluted. Detailed botanical description refers to Pedley (1975).

3.1.1 Leaves (phyllodes)

The mature phyllodes of *Acacia mangium* are very large, generally ranging from 11 to 27 cm in length and 3 to 10 cm in width. They are borne on strongly angled, glabrous, and sturdy branchlets. They are dark green and smooth, with a smooth pulvinus that is 0.6 to 1 cm long. The phyllodes are

distinguished by four (occasionally three or five) major longitudinal nerves that are basally coalescent but distinct from the lower margin. Minor nerves profusely anastomosis to create a noticeable reticulum.

3.1.2 Growth phenology

A gland (extra floral nectary) is prominent. Given ideal circumstances, *Acacia mangium* may grow all year. In Thailand, it has been noted that in January-February, the mix of little rainfall and chilly temperatures causes growth to slow down or stop entirely. In April, trees begin to grow vigorously once more prior to the start of the wet season (Atipanumpai, 1989) [3].

3.1.3 Flowering Phenology

Phenology of flowering *Acacia* flower early Mergen *et al.* (1983) found that *Acacia mangium* begins to bloom and bear fruit 18 to 20 months after planting. Mature fruits arise three to four months following the flowering period. From flower bud development to pod maturity, about 199 days pass Zakaria (1993). Varies over its native and planted range. Naturally, its blooms occur in Australia from February to May, and the seed ripens from October to December (Sedgley *et al.* 1992). Farther north the fruits mature earlier with seed available from July in Indonesia, and late September in Papua New Guinea (Skelton 1987; Turnbull *et al.* 1983). As an exotic, the usual blooming cycle can be upset and flowering can happen all through the year. But usually, one can see a clear peak (Awang and Taylor 1993). In Peninsular Malaysia, the peak occurs in June-July (Zakaria and Kamis 1991); in Sabah, it is January (Sedgley *et al.* 1992); in Taiwan, it is October-November

(Kiang *et al.* 1989); and in Thailand, I met is September (Kijkar 1992)^[5].

3.1.4 Inflorescences, blooms, and fruits

The inflorescence, which is made up of many small flowers, appears as loose spikes up to 10 cm long, either alone or in pairs in the upper axils. The whitish (or cream) blossoms are found in loose spikes 5-12 cm long on peduncles 0.6-1 cm long, either singly or in pairs in the upper axils. The seed pods are linear, tightly coiled when ripe, occasionally tightly spirally coiled, somewhat woody, 7-8 cm in length, and 0.3-0.5 cm in breadth. The seeds are black and lustrous, longitudinal, ovate to oblong 3-5x2-3 mm with a yellow or vivid orange (occasionally red) funicle.

4. Reproductive Biology and Breeding System

Floral Biology *Acacia mangium* blossom has regular symmetry and has five sepals, five petals, many stamens, and one gynoecium. Particularly in the early morning when single blossoms are in bloom, its delicate and sweet aroma stands out. Zakaria 1993). Non-papillate, stigma has a diameter of 63 microns and forms a cup-shaped indentation

at the apex of the style. Stigma and anthers share the same plane. The anther is bilobed and 183 microns in size. Every lobe contains four distinct loculi surrounding a polyad (composite pollen grains). The polyad has a diameter of 30 to 40 microns and is spherical in form; each polyad comprises sixteen pollens. There are around 113 stamens every flower on average. Usually covered in small hairs, the ovary is sessile and contains 12 to 14 ovules each. Most flowers are hermaphroditic. In some inflorescence, however, staminate flowers are also found.

5. Seed Characteristics

Acacia mangium are typically small to medium in size, elliptical to oval in shape, and hard, impermeable seed coat (testa), which is responsible for physical dormancy and protection against adverse environmental conditions. The seed coat is thick and contributes to long-term viability by preventing water imbibition under unfavorable conditions. Studies have reported that *Acacia mangium* seeds are generally dark brown to black and exhibit morphological adaptations such as a pleurogram, a characteristic feature of many *Acacia* species. (Hegde, M. *Et al.*, 2013)^[41].

Table 1: Factors Affecting Treatment Efficiency

S. No.	Factor	Description	Impact on Treatment Efficiency	Citations
1	Seed Coat Thickness	Thickness and hardness of seed coat vary among species.	Thick and hard seed coats reduce water permeability, requiring stronger treatments like scarification.	Baskin & Baskin (2004) ^[11]
2	Treatment Duration	Length of exposure to treatment (hot water, acid, etc.).	Insufficient duration leads to poor germination, while excessive duration may damage embryo.	Hartmann <i>et al.</i> (2011) ^[38]
3	Temperature	Temperature used during treatment or germination.	Optimal temperature enhances enzyme activity and germination; extreme temperatures may reduce viability.	Taiz <i>et al.</i> (2015) ^[59]
4	Chemical Concentration	Concentration of chemicals like H ₂ SO ₄ or GA ₃ used in treatment.	Proper concentration improves germination; high concentration may be toxic to seeds.	Bewley & Black (1994)
5	Seed Maturity	Stage of seed development at harvest.	Mature seeds show higher viability and better response to treatments than immature seeds.	Baskin & Baskin (2004) ^[11]
6	Moisture Content	Initial moisture level in seeds before treatment.	Proper moisture improves imbibition; too much or too little moisture affects germination negatively.	Bewley & Black (1994) ^[14]
7	Species Variation	Genetic and physiological differences among species.	Different species respond differently to the same treatment method.	Baskin & Baskin (2004) ^[11]
8	Storage Conditions	Conditions under which seeds are stored (temperature, humidity).	Poor storage reduces seed viability and treatment effectiveness.	Hartmann <i>et al.</i> (2011) ^[38]

6. Dormancy in Seed

Seed dormancy is a physiological condition that keeps a viable seed from germinating even when the circumstances are right for growth (Baskin and Baskin, 2004)^[11]. The period of dormancy differs considerably between species, with some seeds retaining viability for months while others

lose their capacity to germinate fast. Seeds are made up of an inner embryo that will grow into a plant and an outer protective shell. Water infiltrates the seed coat, causing it to swell and start the plant's development (Bargah *et al.*, 2024)^[9].

Table 2: Types of Seed Dormancy

S. No.	Type of Dormancy	Description	Examples / Features	Citations
1	Seed Dormancy	Seed dormancy is a physiological condition that prevents viable seeds from germinating even under favorable conditions. Dormancy period varies among species; some seeds remain viable for months while others lose viability quickly. Water penetration through seed coat initiates swelling and germination.	General seed structure consists of embryo and protective seed coat.	Baskin & Baskin (2004); Bargah <i>et al.</i> (2024) ^[9, 11]
2	Physiological Dormancy	Dormancy caused by physiological factors within the embryo or surrounding tissues such as endosperm. Freshly matured seeds with non-deep physiological dormancy germinate only under limited temperature conditions.	Common in <i>Fagus</i> , <i>Pinus</i> , <i>Eucalyptus</i> .	Baskin & Baskin (2004) ^[11]
3	Morphological Dormancy	Occurs in seeds with underdeveloped embryos that require additional time for embryo growth before germination.	Seeds with immature embryos.	Kumar <i>et al.</i> (2024)
4	Physical Dormancy	Caused by impermeable seed coat due to thick-walled, cutinized macroscleroid cells preventing water uptake. Germination is promoted through scarification or hot water treatment.	Mechanical scarification, chemical scarification, boiling water soaking.	Baskin & Baskin (2004) ^[11]

6.1 Physiological Dormancy: *Fagus*, *Pinus*, and *Eucalyptus*, among other species, often exhibit this kind of dormancy. The embryo or the surrounding endosperm tissues cause it to be triggered. Freshly developed seeds with non-deep physiological dormancy either cannot germinate at any temperature or can only germinate within a small temperature range.

6.2 Morphological Dormancy: This kind of dormancy affects seeds with undeveloped embryos, necessitating more time for the embryo to develop before germination can take place (Kumar *et al.*, 2024).

6.3 Physical Dormancy: When a layer of thick-walled, cutinized macroscleroid cells makes seed coverings impenetrable to water, this form of dormancy develops. Several treatments, such as mechanical or chemical scarification or soaking in boiling water, are therefore, utilized to stimulate germination in seeds having water-impermeable coatings.

7 Seed Treatment

Seed treatment is the process of applying physical, chemical, or biological agents to seeds prior to planting to

enhance germination, promote seedling vitality and guard against diseases, pests, and environmental stressors. Seed treatment aims at enhancing the general success of seed germination and establishment, so resulting in more robust and more prolific plants. Although certain seeds naturally emerge from dormancy over time, others require unique pre-treatments for germination. One of the biggest obstacles to germination is seed dormancy, so pre-sowing treatments are absolutely vital. Effective ways to break seed dormancy before sowing include scarification (mechanical or chemical), water soaking (hot or cold), chemical treatments, plant growth regulators, or alternating wetting and drying. Many approaches have been utilized to encourage germination in seeds with water impermeable coatings, including mechanical and chemical scarification, soaking in boiling or hot water. Including cold stratification, therapy with gibberellic acid (GA₃), sodium hypochlorite, scarring, or heat treatment can be used for seeds having water-permeable coatings.

Table 3: Different Pre-Sowing Treatments and Their Methods

S. No.	Seed Treatment Method	Description	Examples / Results	Citations
1	Hot Water Treatment	Seeds with hard coats are soaked in hot/boiling water (2-48 hours) to soften the seed coat and improve germination.	Used for <i>Albizia</i> , <i>Acacia</i> , <i>Cassia</i> , <i>Poplar</i> , <i>Leucaena leucocephala</i> .	—
2	Smoke Treatment	Smoke acts as a germination stimulant in both fire-dependent and non-fire-dependent species; useful in restoration and conservation.	Chaparral (Southern California); Fynbos (South Africa); Kwongan (Australia); Mediterranean basin; Improved germination.	Keeley & Pizzorno (1986); De Lange & Boucher (1990); Dixon <i>et al.</i> (1995); Crosti <i>et al.</i> (2006); Jäger <i>et al.</i> (1996); Light & Van Staden (2004); Brown & Van Staden (1998); Brown & Botha (2004)
3	Acid Scarification	Seeds are treated with concentrated H ₂ SO ₄ to weaken the seed coat and enhance water absorption.	<i>Semecarpus anacardium</i> → 74.67% (1 min); <i>Acacia auriculiformis</i> → 92-96% (5-10 min).	Olatunji <i>et al.</i> (2013)
4	Mechanical Scarification	Physical methods like nicking, rubbing, or sanding break hard seed coats without damaging embryos.	<i>Gliricidia sepium</i> ; <i>Melia azedarach</i> (80%); <i>Acacia auriculiformis</i> (78%); <i>Acacia catechu</i> ; <i>Cassia fistula</i> .	Bargah <i>et al.</i> (2025) ^[8]
5	Gibberellic Acid (GA ₃) Treatment	GA ₃ enhances germination by activating enzymes, mobilizing stored food, and promoting faster root and shoot growth.	Increases germination by ~15-30%; effective in <i>Acacia mangium</i> and other forestry species.	Bewley & Black (1994); Hartmann <i>et al.</i> (2011); Taiz <i>et al.</i> (2015) ^[14, 38, 59]

Table 4: Comparison of Physical, Chemical, and Thermal Treatments

S. No.	Treatment Type	Method	Mechanism	Advantages	Limitations	Examples	Citations
1	Physical Treatment	Mechanical scarification (nicking, sanding, rubbing)	Breaks hard seed coat physically, allowing water and oxygen entry	Simple, low cost, no chemicals required, effective for hard seeds	Risk of embryo damage if not done carefully; labor-intensive	<i>Acacia catechu</i> , <i>Cassia fistula</i> , <i>Melia azedarach</i> , <i>Gliricidia sepium</i>	Bargah <i>et al.</i> (2025) ^[8]
2	Chemical Treatment	Acid scarification (H ₂ SO ₄), growth regulators (GA ₃)	Weakens seed coat (acid) or stimulates enzyme activity and embryo growth (GA ₃)	Highly effective, uniform germination, improves germination percentage	Hazardous chemicals, requires precision, higher cost	<i>Acacia auriculiformis</i> (92-96%), <i>Semecarpus anacardium</i> (74.67%), <i>Acacia mangium</i>	Olatunji <i>et al.</i> (2013); Bewley & Black (1994); Hartmann <i>et al.</i> (2011); Taiz <i>et al.</i> (2015) ^[14, 38, 59]
3	Thermal Treatment	Hot water treatment, smoke treatment	Heat softens seed coat; smoke chemicals stimulate germination	Easy to apply, eco-friendly (especially smoke), suitable for large seed lots	Overheating may damage seeds; variable effectiveness across species	<i>Albizia</i> , <i>Acacia</i> , <i>Leucaena leucocephala</i> ; fire-prone ecosystems	Keeley & Pizzorno (1986); De Lange & Boucher (1990); Dixon <i>et al.</i> (1995); Crosti <i>et al.</i> (2006); Light & Van Staden (2004)

7.1 Different Seed Treatment

7.1.1 Hot Water treatment: Hot water soak an excellent technique to increase germination is to soak hard-coated seeds in boiling water. For seeds having hard outer coverings, including Albizia, Acacia, Cassia, Poplars, and Leucaena leucocephala, this approach is often applied. Depending on the species, the seeds are soaked in hot water for two to forty-eight hours.

7.1.2 Smoke Treatment: Smoke created by fires is crucial for restoring several plant communities in semi-arid areas, such as chaparral in southern California (Keeley and Pizzorno, 1986), fynbos in South Africa (De Lange and Boucher, 1990), Kwongan in Australia (Dixon *et al.*, 1995), and the Mediterranean basin (Crostit *et al.*, 2006). Smoke is currently well known as a germination stimulus for fire-dependent as well as non-fire-dependent plant species (Jäger *et al.*, 1996; Light and Van Staden, 2004; Light *et al.*, 2005). Smoke treatments have also shown promise in the propagation of economically important wild plants, as germination percentage can be increased significantly (Brown and Van Staden, 1998; Brown and Botha, 2004). Therefore, smoke and smoke solutions show much promise for use in gardening, farming, weed control, habitat restoration, and conservation techniques (Roche *et al.*, 1997; Boucher and Meets, 2004; Light and Van Staden, 2004).

7.1.3 Acid scarification: A common approach to weaken the seed coat is to steep the seeds in concentrated sulfuric acid. Sulfuric acid is believed to help the seeds absorb water by exposing the lumens of the macrosclereid cells and breaking down the seed coat. Semicarpus nanacardium seeds treated with 98% concentrated H₂SO₄ for one minute reached a maximum germination rate of 74.67%. According to Olatunji *et al.* (2013), Acacia auriculoformis seeds treated with concentrated H₂SO₄ for 5-10 minutes had a germination rate of 92-96%.

7.1.4 Mechanical Scarification

Knuckling and sanding scarification (mechanical) Breaking the hard, impenetrable seed coatings of species including Acacia catechu, A. Nilotica, Albizia spp., and Cassia fistula requires mechanical techniques. Research has demonstrated that knuckling Gliricidia sepium seed distal ends raises germination percentages of 80% and 78%, respectively, were produced by sandpaper scarification of seeds from Melia azedarach and Acacia auriculoformis. (Bargah *et al.* 2025)^[8].

7.1.5 Gibberellic Acid Treatment

The use of Gibberellic Acid as a seed treatment can really help seeds grow. It makes seeds germinate and grow into seedlings faster. Gibberellic Acid helps seeds by making them produce helpers called enzymes. These enzymes are like tools that help the seed use the food it has stored. This means the seed can grow faster and more seeds will germinate.

When seeds are treated with Gibberellic Acid more of them will germinate. This can be around 15 to 30 percent more than seeds that are not treated. So if only about half of the seeds were growing before now around 70 to 90 percent of them will grow. Gibberellic Acid is also good for the seed because it helps the seed grow stronger. It makes the roots and shoots of the seed grow faster.

Gibberellic Acid works by helping the cells in the seed grow and divide. It also helps the seed overcome problems that might stop it from growing. This makes Gibberellic Acid a good treatment to use on seeds before they are planted. It helps the seeds grow and get established in the ground. Gibberellic Acid is a way to help seeds, like *Acacia mangium* and other forestry species grow. (Bewley and Black, 1994; Hartmann *et al.*, 2011; Taiz *et al.*, 2015)^[14, 38, 59].

Table 5: Summary of Previous Research Studies on *Acacia mangium*

S. No.	Author(s) & Year	Study Focus	Key Findings
1	Koutika & Richardson (2019) ^[43]	Ecology, uses, and invasiveness	<i>Acacia mangium</i> is a fast-growing multipurpose tree widely used in agroforestry and land restoration; improves soil fertility through nitrogen fixation but may become invasive in non-native regions.
2	Hegde <i>et al.</i> (2013) ^[41]	Growth characteristics and distribution	Species grows up to 30 m height; adapted to lowland tropical regions and acidic soils; suitable for plantation forestry.
3	Nirsatmanto (2016) ^[48]	Effect of planting density on growth	Planting density significantly influences early growth and development; improved seeds show better performance under optimized spacing.
4	Buvaneswaran & Navamaniraj (2024) ^[19]	Seed and seedling variability	Significant variation observed in seed traits and seedling growth, useful for selection and breeding programs.
5	Paramitha & Mardji (2015) ^[52]	Nursery growth under different soils	Seedling growth varies with soil type; better performance observed in fertile and well-drained soils.
6	Nath <i>et al.</i> (1990); Venkatesh (2000) ^[46, 62]	Germination and adaptability	Species shows high adaptability to acidic and infertile soils; widely used in social forestry and reforestation programs in India.
7	Nugroho <i>et al.</i> (2018) ^[50]	Physiological growth (gravitropism)	Stem inclination affects growth behavior and tension wood formation, influencing structural stability.
8	Sun <i>et al.</i> (2025) ^[58]	Tissue culture and bud induction	Efficient bud induction achieved without certain nitrogen sources, supporting advanced propagation techniques.

8. Conclusion

The provided review explores the multi-faceted role of *Acacia mangium*, a fast-growing tropical legume that serves as a cornerstone for global agroforestry while posing significant ecological risks. While it is highly valued for its

ability to fix atmospheric nitrogen, sequester carbon, and thrive in acidic, nutrient-poor soils (pH < 4), its aggressive adaptability has led to its classification as an invasive species in several continents, creating a phenomenon known as "invasion debt." A critical portion of the study focuses on

overcoming the species' inherent physical seed dormancy caused by a thick, water-impermeable seed coat; research highlights that specialized pre-sowing treatments ranging from thermal (hot water) and mechanical scarification to chemical etching with H_2SO_4 and hormonal stimulation with Gibberellic Acid (GA_3) are essential to achieve high germination rates (up to 96%). Ultimately, the paper emphasizes the need for a balanced management approach that maximizes the economic and silvicultural benefits of *Acacia mangium* while mitigating the long-term biological invasion threats to native ecosystems.

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