**Enhancing Germination of Forest Tree Seeds in Chhattisgarh through PGR-Based Treatments: A Review**

**Abstract**

Plant growth regulators (PGRs) are forest tree seed germinator, it is necessary to demonstrate that PGRs are involved in the mechanisms that control both the induction of dormancy and the release from it, and that these mechanisms operate in woody plant seeds. The establishment of plantations, recognizing the current need for sustainable alternatives for depleting natural forests, has gained significance for industrial and domestic wood production on both large and small scales. This review examines four known concepts of seed dormancy and discusses the published evidence linking PGRs to tree seed germination. Tree seed germination influenced by a variety of external and internal factors, with PGRs playing a key role among them. However, the mechanisms through which this control occurs can differ greatly, ranging from physical to metabolic processes. The successful establishment of tree species depends on factors such as the quality of planting material, soil condition, water availability for irrigation, and protection measures in place. Many tree species face challenges with seed germination due to both external and internal factors, leading to seed dormancy. Plant growth regulators such as Auxins (IAA, IBA, 2-4D, 4-CPA), Gibberellic acid (GA3), Cytokinins (Kinetin, Zeatin, Benzyl adenine), Ethylene (Etheral), and Abscisic acid (Dormins, Phaseic Acid) are used in various concentrations to improve tree seed germination. It can be concluded that seed morphological parameters are directly linked to germination, with a higher vigor index leading to faster germination. Additionally, seeds collected shortly after dispersal or ripening tend to be recalcitrant, but sowing them within a month of collection ensures high germination rates.

**Key words:** Plant Growth Regulators, Seed, Scarification, Dormancy, Germination.

**Introduction**

Seed germination is a complex process that leads to the resumption of active growth in the embryonic axis, rupture of the seed cover and emergence of the young plants. For physiologists and biochemists, germination is complete when the radicle ruptures and the cover becomes visible. For seed technologists, foresters, nursery growers, etc. however, germination is a complex process that leads to the resumption of active embryonic growth and continued growth and development until a potentially independent seedling is formed (Vicente & Benito Garzón, 2024; Boro et al., 2024). Plantation of the forest tree species has emerged as a crucial initiative in the forestry sector to meet the increasing demand for timber, non-timber forest produce (NTFP), fodder, fuelwood, etc., both from natural forests and plantation forestry (Bhardwaj *et al.,* 2023). The establishment of plantations, recognizing the current need for sustainable alternatives for depleting natural forests, has gained significance for industrial and domestic wood production on both large and small scales (Kumar *et al.,* 2022a). A critical concern in this context is the insufficient awareness regarding suitable pre-sowing seed treatments for various tree species. This knowledge gap poses a significant obstacle to the mass production and conservation efforts of many species (Chandra *et al.,*2021). Sal seeds are harvested from the *Shorea robusta* species and contain 13-14% oil. This oil serves as a substitute for cocoa butter and is used in confectionery and other food products. The residual oil cake, which has a protein content of10-12%, is used as a high-protein feed for chickens and as organic fertilizer in agriculture. The yield of Sal seeds can fluctuate from year to year. Collection typically occurs from June to Julyeach year. Key Sal seed producing districts in Chhattisgarh include Jagdalpur, Keshkal,SouthKondagaon, East Bhanupratappur, Gariyaband, Dhamtari, Dharamjaigarh, Korba, Jashpur,Balrampur, Surguja, and Korea.Sal.(Bargah*et al.,*2024). Dormancy is an inherent state of growth that

is found among all life forms. However, dormancy of seeds in plants elucidated as inborn limitation on germination under circumstances that would otherwise encourage germination in non-dormant seeds. In favorable conditions, dormancy is state which enable seeds to avoid germination. Plants also disperse their progeny across time to avoid risk against uncertain environmental conditions by producing seeds with varying levels of dormancy (Chandra et al., 2024).

Addressing this concern necessitates focused research into innovative seed technologies, considering the growing importance of this domain in the global crop protection markets, as emphasized by Sharma *et al.,* (2015). A comprehensive understanding of seed science, which includes aspects like seed collection, storage, viability, and germination, is essential for improving the success of restoration efforts. Seed germination is the process in which the embryo develops into a seedling under favorable conditions (Kumar *et al.,* 2023). It involves a series of physiological, biochemical, and morphological changes that together lead to germination. This complex process can be broken down into three main phases: Phase I, marked by rapid water absorption; Phase II, where metabolism reactivates, cell elongation occurs, and chitting takes place; and Phase III, characterized by rapid cell division alongside radicle growth. Phase II, in particular, is crucial, as it involves the reactivation of vital physiological and biochemical processes such as the breakdown of food reserves, macromolecular biosynthesis, respiration, restructuring of subcellular structures, and cell elongation, all of which are critical for initiating germination (Bonsager*et al.,*  2010; Vaishnav *et al.,* 2025).

**1. Seed germination**

Seed germination is the initial step in the life cycle of plants, which begins when the inactive dry seed imbibes water and is completed with the protrusion of the radicle from the seed coat (Aashutosh *et al.,* 2024). Seed germination is a complex process which involves several signals and is influenced by both intrinsic and extrinsic factors (Chandra *et al.,* 2024). Seed Germination types are shown in Fig. 1.

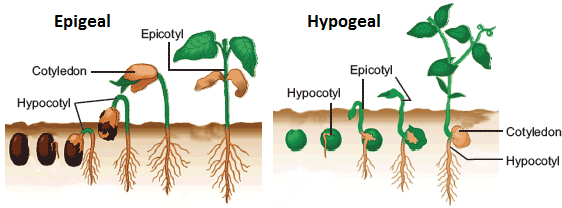
**Fig 1. Seed germination can be classified into two types based on the outcome of the cotyledons.**

**1.2 Epigeal Germination**

This process involves the cotyledon being pushed out of the soil due to the rapid growth and elongation of the hypocotyl, as seen in species like Acacia, Adenanthera, Albizia, Cassia, Dipteryx, Diphysa, Erythrina, Gliricidia, Haematoxylum, Hymenaea, Hymenolobium, Parkia, Parkinsonia, Pterocarpus, Samaneasaman, Sclerolobium, Tamarindus, Casuarina, Annona, Cordia alliodora, Myrcia, Capparis, Cedrela, Melia, Zizyphus, Anacardium excelsum, Jacaranda, Ulmus, Ilex, and Elaeocarpus. Epigeal and Hypogeal seed germination shown in (Fig:2).

**1.3 Hypogeal Germination**

In this type, cotyledons remain below the soil due to the rapid elongation of the epicotyl. This predominantly occurs in monocotyledonous seeds, e.g., *Calophyllum, Swartzia, Syzygium, Swietenia, Prunus, Sapindus, Terminalia catappa,* etc.



**Fig 2.Epigeal and Hypogeal seed germination.**

**2. Mechanism of Seed Germination**

Germination is a multifaceted biological process that begins with imbibition, where the seed absorbs water. Following this, enzymes are activated to convert starches into sugars, supplying the embryo with vital nutrients (Tiwari *et al.,* 2024). The initial indication of germination is the swelling of the radicle, marking the start of growth. The time required for seedlings to emerge depends on the size of the seed. Larger seeds, with more nutrient reserves, can germinate at greater depths and extend their epicotyl to the surface. Smaller seeds, however, tend to emerge more rapidly and typically grow closer to the surface (Bhardwaj *et al.,* 2024).

**2.1 Factors Affecting Seed Germination**

Seed germination is affected by both internal and external factors. Internal factors, such as genetic traits, seed viability, and dormancy, are inherited from the parent plants and significantly influence the seed’s germination potential and subsequent growth (Limanpure and Kumar, 2018). External factors include moisture, temperature, oxygen, light, and soil conditions. Additionally, internal aspects like the maturity of the embryo, seed viability, and dormancy play a critical role in the germination process. A thorough understanding and manipulation of these

factors are essential for optimizing the germination of tree seedlings. Factors Affecting Seed Germination shown in Fig 3.

**Fig 3.Factors Affecting Seed Germination**

**3. Seed Dormancy**

Seed dormancy is a physiological condition that prevents a viable seed from germinating, even when conditions are ideal for growth (Baskin and Baskin, 2004). The duration of dormancy varies significantly among species, with some seeds remaining viable for months, while others quickly lose their ability to germinate. Seeds consist of an outer protective coat and an inner embryo that eventually develops into a plant. Germination begins when water enters the seed coat, causing it to swell and triggering the growth of the plant (Bargah*et al.,* 2024).Types of seed Dormancies shown in (Fig:4).

**Fig 4. Types of seed Dormancies.**

**1.Physiological Dormancy**

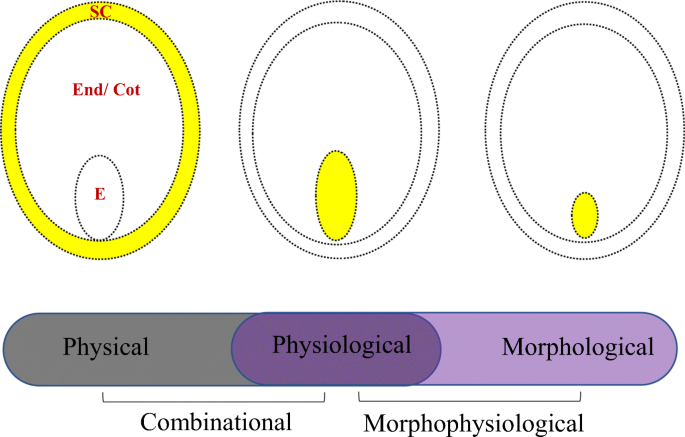
This type of dormancy is commonly found in species like Fagus, Pinus, and Eucalyptus. It is triggered by the embryo or the surrounding endosperm tissues. Freshly matured seeds with non-deep physiological dormancy either cannot germinate at any temperature or can only germinate within a limited temperature range.

**2.Morphological Dormancy**

Seeds with underdeveloped embryos experience this type of dormancy, requiring additional time for the embryo to mature before germination can occur (Kumar *et al.,* 2024).

**3.Physical Dormancy**

This type of dormancy occurs when seed coats are impermeable to water due to a layer of thick-walled, cutinized macroscleroid cells. To overcome this, various treatments such as mechanical or chemical scarification, or soaking in boiling water, are used to promote germination in seeds with water-impermeable coats. For seeds with water-permeable coats, methods like cold stratification, treatment with gibberellic acid (GA3), sodium hypochlorite, scarification, or heat treatment can be applied (Baskin and Baskin, 2020).Structure of seed Dormancies shown in (Fig:5)



**Fig 5.Structure of Seed Dormancies.**

Various techniques have been used to stimulate germination in seeds with water-impermeable coats, such as mechanical and chemical scarification, or soaking in boiling or hot water. In contrast, seeds with water-permeable coats can benefit from treatments like cold stratification, gibberellic acid (GA3), sodium hypochlorite, as well as scarification or heat application (Baskin and Baskin, 2020). While some seeds naturally break dormancy over time, others need specific pre-treatments to germinate. Seed dormancy presents a major challenge to germination, making pre-sowing treatments essential. Methods such as scarification (mechanical or acid), water soaking (hot or cold), chemical applications, plant growth regulators, or alternating wetting and drying before sowing are effective in overcoming seed dormancy (Kumar *et al.,* 2022b).

**1. Overcoming Seed-Coat Dormancy**

Common methods for breaking seed-coat dormancy include puncturing or scarifying the seed coat using techniques like piercing, nicking, chipping, or filing with tools such as a knife, needle, or sandpaper.

**2. Overcoming Embryo Dormancy**

Several effective treatments are available to break embryo dormancy:

**a)Pre-chilling (Cold Stratification)**

Seeds are placed in containers with a moistened germination medium and stored at 3°-5°C in a refrigerator for 7-14 days. Seeds from species that thrive in cold climates, especially perennials that endure extended snow cover and severe winters, require much lower temperatures for longer periods to achieve effective stratification. (Cuena-Lombraña*et al.,*  2018).

**b)Hormonal Treatment**

Dormancy can be overcome by applying plant hormones such as abscisic acid (ABA), gibberellin (GA3), ethylene, and jasmonicacid (JAS). Among these, gibberellin (GA3) is the most effective in promoting germination (Shu *et al.,* 2016). To test germination, germination paper is moistened with a 0.05% gibberellic acid (GA3) solution, which is prepared by dissolving 500 mg of GA3 in 1 liter of water. The process works by softening the endosperm, encouraging embryo growth, and enabling the seedling to break through the seed coat and emerge.

**c)Chemical Scarification**

The impermeability of seed coats, which hinders water absorption, can be addressed through chemical scarification. This is particularly challenging for seeds from tree species in dry and semi-arid regions, where seed coat impermeability affects germination (Kheloufi *et al.,*  2018). Dormancy can be broken by soaking seeds in various chemicals, such as acidic or basic solutions, organic solvents, alcohol, disinfectants, or boiling water. Common acids used for scarification include phosphoric acid (ranging from 25% to 75%, depending on the seed type), potassium nitrate, nitric acid, and concentrated sulphuric acid (96%). For potassium nitrate treatment, a 0.2% solution is prepared by dissolving 2 g of potassium nitrate (KNO3) in 1 liter of water.

**d)Light Treatment**

Exposing seeds to strong cool-white and infrared light simulates the natural spring and summer conditions. The light source should be placed near the seeds and remain on for at least 8 hours daily in a moist environment at low temperatures. After the light exposure, seeds should be kept in the dark until germination occurs. Positive effects on germination have been seen with both cool-white and red light, while blue and green light tend to result in lower germination rates (Li and Khan, 2005).

**e) Hot or Cold Water Treatment**

This affordable and farmer-friendly method has been recognized for improving seed germination. It is particularly effective for most medium-sized dry seeds, as it allows them to absorb sufficient water and soften their seed coats. Heat treatment also proves moderately successful in overcoming seed dormancy. Research recommends a combination of 1-30 minutes of acid scarification followed by a one-hour heat treatment at temperatures between 55-77°C to optimize germination, depending on the species (Koutouan-Kontchoi*et al.,*  2020). Additionally, soaking seeds in water for 24-48 hours helps soften tough seeds and remove chemical inhibitors, which promotes better germination (Umarani and Vannangamudi, 2005).

**f) Stratification (Warm and/or Cold)**

Stratification is a technique used to break the hard outer shell of a seed to facilitate germination. This process involves exposing the seed to a moist environment, which helps soften the outer layer, allowing the seed to sprout more easily. There are two types of stratification: cold stratification and warm stratification (D’Este*et al.,*  2019).

**g) Scarification**

Scarification is a method used to break or weaken the tough outer shell of a seed to enhance germination. It involves physically damaging the seed coat by methods such as scratching, nicking, or rubbing it with sandpaper or a file. This process is commonly applied to seeds that have a hard outer covering, which prevents water and air from reaching the embryo (D’Este*et al.,*  2019).

**4. Seed Treatment**

Seed treatment refers to the application of physical, chemical, or biological methods to seeds before sowing to enhance their germination, improve seedling vigor, and protect them from diseases, pests, and environmental stresses. The goal of seed treatment is to improve the overall

success of seed germination and establishment, leading to healthier and more productive plants (Harris *et al.,* 2009).Types of seed treatment shown in(Fig 6) and (Table 1)

**Fig 6. Types of seed treatment.**

**Table 1.Types of Seed Treatment**

|  |  |  |
| --- | --- | --- |
| Type of Seed Treatment | Description | Purpose |
| Scarification | Mechanical or chemical abrasion of the seed coat to promote germination. | To break physical dormancy and enhance germination rates. |
| Stratification | Cooling seeds for a period to simulate winter conditions. | To break physiological dormancy and synchronize germination. |
| Priming | Pre-soaking seeds in a solution to initiate germination processes without full germination. | To improve seed vigor and uniformity of germination. |
| Hot Water Treatment | Immersing seeds in hot water for a specific time. | To kill pathogens and break dormancy. |
| Chemical Treatment | Using fungicides, insecticides, or growth regulators to treat seeds. | To protect seeds from diseases and pests. |
| Coating | Applying a layer of materials (e.g., polymers, nutrients) to the seed surface. | To improve seed handling, protect seeds, and supply nutrients. |
| Dry Heat Treatment | Exposing seeds to high temperatures for a short period. | To kill pathogens and insects. |
|  |  |  |

**4.1 Types of seed treatment**

**4.1.1 Cold Water**

Soaking seeds in cold water for 24 to 48 hours before planting has been studied as a beneficial pre-treatment technique. Hossain *et al.* (2005) found that *Terminalia chebula* seeds had the highest germination rate (66.7%) when subjected to a 48-hour cold-water soak, with the germination rate rising to 73% when the seeds were de-pulped prior to soaking.

**4.1.2 Soaking in Hot Water**

Soaking seeds with hard coats in boiling water has proven to be an effective method for enhancing germination. This technique is commonly used for seeds with tough outer shells, such as Albizia, Acacia, Cassia, Poplars, and Leucaena leucocephala. The treatment involves soaking the seeds in hot water for 2 to 48 hours, depending on the species.

**4.1.3 Alternate Wetting and Drying**

This method is particularly effective for seeds with thicker seed coats (Dwivedi*et al*., 1993). Similarly, Pamei *et al*., (2017) observed that *Tectona grandis* seeds, when subjected to alternating periods of 12 hours of wetting and 12 hours of drying over 8 days, had the highest germination rate (43.3%), along with the best seedling height and root length.

**4.1.4 Knuckling and Sandpaper Scarification (Mechanical)**

Mechanical methods are essential in breaking the tough, impermeable seed coats of species like *Acacia catechu*, *A. nilotica*, *Albizia spp.,* and *Cassia fistula*. Studies have shown that knuckling the distal ends of *Gliricidi asepium* seeds improves germination without harming the embryo (Chichaghare *et al.,*  2020). Sandpaper scarification of seeds from *Melia azedarach* and *Acacia auriculoformis* resulted in impressive germination rates of 80% and 78%, respectively (Azad *et al.,*  2010, 2011).

**4.1.5 Nitrogenous Compounds**

The influence of nitrate compounds on seed germination, particularly when combined with factors such as temperature and light, is well-documented (Eremrena and Mensah, 2016). Potassium nitrate (KNO3) is a commonly used chemical for breaking seed dormancy and stimulating germination. Solutions of 0.1–0.2% KNO3 have been found to be effective in enhancing germination in species that exhibit low or shallow dormancy patterns (Gashi *et al.,*  2012). KNO3 is also frequently used in seed priming, as it improves both the uniformity and speed of germination (Tapfumaneyi *et al.,* 2023).

**4.1.6 Acid Scarification**

Soaking seeds in concentrated sulfuric acid is a widely used method to soften the seed coat. Sulfuric acid is thought to break down the seed coat and expose the lumens of the macrosclereid cells, aiding in water absorption (Nikoleave,1977). For instance, Semicarpusanacardium seeds treated with 98% concentrated H2SO4 for one minute achieved the highest germination percentage of 74.67%. Olatunji *et al.* (2013) found that Acacia auriculoformis seeds treated with concentrated H2SO4 for 5-10 minutes had a germination rate between 92-96%.

**5. Seed Priming Treatments**

Seed priming is a preparatory technique applied before sowing, which involves hydrating seeds enough to activate metabolic processes without allowing the radicle to emerge (Rehman *et al.,*  2011). Natural priming has been beneficial for the germination of tropical tree species such as *Albizia saman, Cedrela odorata,* and *Swietenia macrophylla*.(Verma *et al*., 2024)

**5.1 Hormonal Regulation in Seed Germination**

Plant growth regulators are crucial in seed germination, with hormones like GA, ABA, auxin, and ethylene having a significant impact (Han and Yang, 2015). Ethylene may play a key role in regulating dormancy through its interaction with GA metabolism. Seed treatments with GA solutions have been shown to improve germination parameters, enhance seed vigor, and ensure more uniform germination (Maharana *et al.,*  2018). Moreover, using plant growth regulators like GA3, IAA, and IBA along with cold stratification has proven effective in breaking dormancy and improving germination across various species (Iralu *et al.,* 2019).Types of plant growth hormones shown in(Fig:7) and (Table 2)

**5.2 ABA (Abscisic Acid)**

ABA Plays a positive role in regulating stomatal activity, seed dormancy, and plant responses to stresses such as flooding (abiotic stress) and pathogen attacks (biotic stress) (Popko *et al.,*  2010). However, it negatively impacts seed germination. For instance, concentrations ranging from 1 to 10 μM can inhibit the germination of seeds in plants like *Arabidopsis thaliana*(Muller *et al.,*  2006).

**5.3 Ethylene**

The simplest biochemical structure among plant hormones, has a broad impact on various plant processes. Like cytokinin, ethylene is perceived by a kinase receptor, which is a two-component protein. However, the ethylene receptor is located in the endoplasmic reticulum membrane (Santner *et al.,*  2009). While ethylene influences a range of plant activities, including tissue.

**5.4 Gibberellins**

Gibberellins are diterpenoid compounds that regulate plant growth and are widely used in modern agriculture. They were first isolated in 1938 from the metabolic products of the rice pathogenic fungus ‘Gibberellafujikuroi’(Santner *et al.,*  2009). The biosynthesis of gibberellins begins with geranyl diphosphate and involves a series of enzymatic steps.

**5.6 Auxin**

Auxin is a plant hormone that plays a crucial role in regulating various functions such as cell cycling, growth, and development, as well as the formation of vascular tissues and pollen. It also influences the development of other plant parts**.** The growth and development of different plant organs, including the embryo, leaves, and roots, are thought to be controlled by the transport of auxin (Benjamins and Scheres, 2008).

**5.7 Cytokinins**

Cytokininsare plant hormones derived from adenine molecules, with a side chain attached to the N6 position. They were first discovered by Miller in the 1950s due to their ability to promote plant cell division. Cytokinins regulate various plant processes, including seed germination, and are active throughout all stages of germination (Riefler *et al.,* 2006).

**5.8 Brassinosteroids(BR)**

BR are a group of plant hormones that share similarities with steroid hormones found in other organisms (Arora *et al.,* 2008). These hormones are derived from cholestane hydroxylated derivatives, with variations in the structure of the C-17 side chain and rings determining differences in the hormonal structure.

**Fig 7. Types of plant growth hormones.**

**Table2. Types of plant growth hormones**

|  |  |  |
| --- | --- | --- |
| Type of Plant Growth Hormone | Function | Example Effects on Forest Seeds |
|  |  |  |
| Auxins | Promote cell elongation, root formation, and seedling establishment. | Enhances root development and seedling growth in forest species. |
| Gibberellins (GAs) | Stimulate seed germination and break seed dormancy. | Helps in breaking seed dormancy and promoting germination in forest seeds. |
| Cytokinins | Promote cell division and shoot formation; delay senescence. | Can enhance seedling growth and recovery after planting. |
| Abscisic Acid (ABA) | Regulates seed dormancy and stress responses; controls stomatal closure. | Maintains seed dormancy and aids in stress tolerance during seedling establishment |
| Ethylene | Influences seedling growth, fruit ripening, and stress responses. | Can impact seedling acclimatization and stress responses during early growth stages |
| Brassinosteroids | Promote cell elongation, stress tolerance, and vascular differentiation | Enhances growth and stress resistance in forest seedlings |
| Jasmonic Acid (JA) | Mediates defense responses and stress adaptation. | Plays a role in stress responses and pest resistance in forest species |
| Salicylicacid | Promote germination under high salinity, Influences on photosynthesis, enzyme activities, flowering etc. | Plays a role in stress responses |

**6. Mechanistic Understanding of Growth Hormone Influence on Seedling Germination**

Plant growth regulators are chemical compounds that control various aspects of plant development and growth (Srivastava, 2002). Seed coats that are impermeable to oxygen can hinder germination, but hormonal treatments have proven effective in overcoming this obstacle. A key balance between Abscisic Acid (ABA) and Gibberellic Acid (GA) governs dormancy, with ABA inhibiting embryo growth and maintaining dormancy by being synthesized at the radical (Sabagh *et al.,* 2021). Gibberellins, particularly gibberellic acid (GA3), play a central role in promoting seed germination by breaking dormancy (Bargah*et al*.,2024) GA3, commonly used in seed treatments, triggers germination by stimulating enzyme production and cell elongation in the embryo, thus facilitating the germination process. Gibberellins lower the levels of abscisic acid, a hormone linked to seed dormancy, signaling to the seed that the conditions are suitable for germination(Sabagh *et al.,* 2021). Cytokinins are mainly present in growing tissues such as roots, embryos, and fruits, where cell division takes place. They control a variety of functions, including root development, the formation and maintenance of shoot meristems, organ development, seed germination, fruit development, delay of senescence, and response to stress (Sharma *et al.,* 2022). Cytokinins help delay leaf senescence, promote mitosis, and stimulate meristem differentiation in both shoots and roots. They often interact with auxin and other hormones like gibberellins to regulate plant development (Grobkinsky and Petrasek, 2019). IAA is a widely distributed endogenous auxin in plants, crucial for root growth and seedling establishment following germination. Auxin specifically promotes the development of the radicle (embryonic root) and the primary root system.(minj*et al*.,2024) It plays a vital role in nearly every aspect of root development by regulating transitions between cell division, growth, and differentiation, and establishing the root apical meristem (Roychoudhry and Kepinski, 2022). Ethylene is essential for breaking seed dormancy and regulating the germination process. It significantly aids in promoting seed germination in certain species by counteracting the effects of ABA through the regulation of ABA metabolism and signaling pathways. Ethylene’s role in dormancy release is critical for many species, with effective concentrations for germination of dormant seeds ranging from 0.1 to 200 μL L-1 (Corbineau *et al.,* 2014). Ethylene works in a complex signaling network, interacting with both ABA and GAs, which are key regulators of germination and dormancy. Additionally, ethylene enhances seed germination through antagonistic interactions with ABA and synergistic actions with GAs (Ahammed *et al.,* 2020).

**7. Conclusions**

Plant hormones, produced by both plants and soil bacteria, can profoundly affect seed germination. The collective influence of hormones such as ABA, IAA, cytokinins, ethylene, gibberellins, and brassinosteroids can either enhance or inhibit seed germination, often through complex interactions. Seed treatments present valuable opportunities to overcome seed dormancy, improve germination rates and uniformity, and reduce emergence time. It can be concluded that seed morphological parameters are directly linked to germination, with a higher vigor index leading to faster germination. Additionally, seeds collected shortly after dispersal or ripening tend to be recalcitrant, but sowing them within a month of collection ensures high germination rates.

Disclaimer (Artificial intelligence)

I hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of this manuscript.

**Reference:**

Aashutosh, K. M., Bhardwaj, A.K., Kumar, R., Chandra, K.K., Kumari, C., Pandey, S.K. (2024). [Impact of Urban Xenobiotics on Mycorrhizal Associations in Urban Plants.](https://neptjournal.com/upload-images/(12)B-4163.pdf)Nature Environment & Pollution Technology, 23(4):1-15.

Azad, M. S., Islam, M. W., Matin, M. A., & Bari, M. A. (2006a). Effect of pre- sowing treatment on seed germination of \*Albizialebbeck\* (L.) Benth. \*South Asian Journal of Agriculture, 1\*(2), 32–34.

Bargah, A. S., Pratap Toppo, D. L. S., Tuteja, S. S., Mankur, M. K., & PainkraandPankaj, D. S. (2024) Effect of nutrient management on growth performance of Geranium (Pelargonium graveolens) under Karanj (Pongamiapinnata) based agroforestry system in Chhattisgarh plain.

Bargah, A.S., Kumar, R., Khandekar, H., Vaishnaw, A.K. (2024). A Status of Different Non Wood Forest Products in Chhattisgarh, India. *International Journal of Plant & Soil Science* 36 (11):23-40. <https://doi.org/10.9734/ijpss/2024/v36i115118>.

Baskin, C. C., & Baskin, J. M. (2020). Breaking seed dormancy during dry storage: A useful tool or major problem for successful restoration via direct seeding? \*Plants, 9\*(5), 636.

Baskin, J. M., & Baskin, C. C. (2004). A classification system for seed dormancy. \*Seed Science Research, 14\*, 1–16.

Bhardwaj A.K., Chandra K.K. and Kumar R. (2023). Mycorrhizal inoculation under water stress conditions and its influence on the benefit of host microbe symbiosis of *Terminalia arjuna* species. *Bulletin of the National Research Centre* 47(89):1-13.<https://doi.org/10.1186/s42269-023-01048-3>

Bhardwaj, A.K., Chandra, K.K., Kumar, R. (2024). [Inoculants of Arbuscular Mycorrhizal Fungi Influence Growth and Biomass of *Terminalia arjuna* under Amendment and AnamendmentEntisol](https://scholar.google.com/citations?view_op=view_citation&hl=en&user=olEbSokAAAAJ&citation_for_view=olEbSokAAAAJ:roLk4NBRz8UC). Mycobiology 52 (3), 183-190.

Bønsager, B. C., Shahpiri, A., Finnie, C., & Svensson, B. (2010). Proteomic and activity profiles of ascorbate– glutathione cycle enzymes in germinating barley embryo. \*Phytochemistry, 71\*(14–15), 1650– 1656.

Chandra K.K., Kumar R. and Baretha G. (2021). Vandalism: A Review for Potential Solutions. Tree Benefits in Urban Environment and Incidences of Tree. (Eds. Bhadouria R., Singh P., Upadhyay S., Tripathi S.), John Wiley & Sons, Inc., Hoboken, NJ, USA.ISBN: 9781119807186.

Chandra, K.K., Kumar, R., Dixit, B., Nayak,P.P., Bhardwaj, A.K., Pandey, S.K. (2024). [Analyzing the Contribution of Moringa oleifera (Lam.) to the CO Stock and Other Advantages for Urban Residents](https://scholar.google.com/citations?view_op=view_citation&hl=en&user=olEbSokAAAAJ&citation_for_view=olEbSokAAAAJ:hC7cP41nSMkC). International Journal of Plant & Soil Science, 36 (10), 305-317.

Dwivedi, A. P. (1993). \*A textbook of silviculture\*. International Book Distributors. 505p.

Eremrena, P. O., & Mensah, S. I. J. (2016). Effect of plant growth regulators and nitrogenous compounds on seed germination of pepper (\*Capsicum frutescens\* L.). \*Applied Science and Environmental Management, 20\*(2), 242–250.

germination of \*Gentiana lutea\* L. subsp. lutea (Gentianaceae). \*Journal of Plant Ecology, 11\*(2), 308–316.

Kheloufi, A., Mansouri, L., Aziz, N., Sahnoune, M., Boukemiche, S., & Ababsa, B. (2018). Breaking seed coat dormancy of six tree species. \*Reforesta, 5\*, 4–14.

Koutouan-Kontchoi, M. N., Phartyal, S. S., Rosbakh, S., Kouassi, E. K., & Poschlod, P. (2020). Seed dormancy and dormancy-breaking conditions of 12 West African woody species with high reforestation potential in the forest- savanna ecotone of Côte d’Ivoire. \*Seed Science and Technology, 48\*(1), 101–116.

Kumar R., Bhardwaj A. K. and Chandra K. K. (2023). Effects of arbuscular mycorrhizal fungi on the germination of *Terminalia arjuna* plants grown in fly ash under nursery conditions. *Forestist,*74: 142-146. DOI:10.5152/forestist.2023.23015

Kumar R., Bhardwaj A. K., Chandra, K. K., Dixit B. and Singh A.K. (2024). Diverse role of mycorrhiza in plant growth and development: Review.*Solovyov Studies ISPU* 72(2):37-61.

Kumar R., Bhardwaj A.K. and Chandra K.K. (2022a). A Review on Agroforestry Practices for Improving Socioeconomic and Environmental Status. *Indian Forester,* 148(5): 474-478.

Kumar, R., Ramchandra, Bhardwaj, A.K., Chandra, K.K. (2022b). [Impacts of varying nitrogen levels on leaf length of onion varieties under poplar based agroforestry system.](https://www.cabidigitallibrary.org/doi/full/10.5555/20230228563) The Indian Forestor, 148(12):1241-1244.

Li, S. M., Zheng, H. X., Zhang, X. S., & Sui, N. (2021). Cytokinins as central regulators during plant growth response. \*Plant Cell Reports, 40\*(2), 271–282. <https://doi.org/10.1007/s00299-020-> 02612-1

Li, W., Liu, X., Khan, M. A., & Yamaguchi, S. (2005). The effect of plant growth regulators, nitric oxide, nitrate, nitrite, and light on the germination of dimorphic seeds of \*Suaeda salsa\* under saline conditions. \*Journal of Plant Research, 118\*, 207–214.

Limanpure Y. and Kumar R. (2018). Effect of Different Levels of Inorganic Fertilizers on the Growth and Yield of Barley (*Hordeumvulgare .L)* Under Teak (*Tectonagrandis*) Based Agrisilviculture System. *Trends in Biosciences,* 11(6):881-886.

Minj, N., Toppo, P., Tuteja, S. S., Singh, L., Mankur, M. K., Bargah, A. S., & Verma, S.(2024) Effect of Different Potting Media on Seeds Germination & Growth of Dahiman (Cordia macleodii Hook.) in Nursery.

Minj, Neha, Pratap Toppo, S. S. Tuteja, Lalji Singh, Manish Kumar Mankur, Alok Singh Bargah, and Sakshi Verma. "Effect of Different Potting Media on Seeds Germination & Growth of Dahiman (Cordia macleodii Hook.) in Nursery."

Pamei, K., Larkin, A., & Kumar, H. (2017). Effect of different treatments on the germination parameters and seedling quality index of \*Tectona grandis\* (Teak) under nursery conditions. \*International Journal of Chemical Studies, 5\*(5), 2418-2424.

Priya Gupta, Damini Sharma, Yamini Baghel, Nalini and Alok Singh Bargah. Physical and biological characteristics of Tamarindus indica: A review. Int. J. Adv. Biochem. Res. 2025;9(6):416-424.

Rashid, A., Harris, D., Hollington, P., & Ali, S.(2004). On-farm seed priming reduces yield losses of mungbean (\*Vigna radiata\*) associated with mungbean yellow mosaic virus in the North West Frontier Province of Pakistan.\*Crop Protection, 23\*, 1119-1124.

Reddy, M. C., Bhargavi, C., Rajendra, M. P., Indu, K., & Babu, H. (2022). A review on seed pre-sowing treatments in forestry applications. \*Journal of Plant Development Science, 14\*(3), 243-251.

Rehman, H. U., Maqsood, S., Basra, A., & Farooq, M. (2011). Field appraisal of seed priming to improve the growth, yield, and quality of direct- seeded rice. \*Turkish Journal of Agriculture, 35\*, 357-365.

Tiwari, R.K.S., Chandra, K.K., Kumar, R., Bhardwaj, A.K., Pandey, S.K., Dixit, B. (2024).[Microbial Biopesticides: An Ecofriendly Plant Protection Measures](https://scholar.google.com/citations?view_op=view_citation&hl=en&user=olEbSokAAAAJ&citation_for_view=olEbSokAAAAJ:_Qo2XoVZTnwC). Environment and Ecology, 42 (4): 1590-1598.

Umarani, R., & Vanangamudi, K. (2005). Pre-storage treatments to improve viability in \*Casuarina equisetifolia\* seeds. \*Madras Agricultural Journal, 92\*(7-9), 484- 491.

Vaishnav, A.K., Kumar, R., Khandekar, H., Bargah, A.S. (2025).Sericulture: A Dynamic Contribution of the Indian Nation. *International Journal of Agriculture Sciences*, 17(1):13317-13321

Verma, Sakshi, Pratap Toppo, Sanjay Kumar Bhariya, Lalji Singh, Manish Kumar Mankur, Alok Singh Bargah, and Neha Minj. "Effect of different potting mixture on seedling growth and performance of wild jackfruit (Artocarpuslacucha Buch.) in nursery."

Yang, F., Fan, Y., Wu, X., Cheng, Y., Liu, Q., Feng, L., Chen, J., Wang, Z., Wang, X., Yong, T., Liu, W., Liu, J., Du, J., Shu, K., & Yang, W. (2018). Auxin-to-gibberellin ratio as a signal for light intensity and quality in regulating soybean growth and matter partitioning. \*Frontiers in Plant Science, 9\*, 1-13.

Vicente, E., & Benito Garzón, M. (2024). Tree Germination Sensitivity to Increasing Temperatures: A Global Meta‐Analysis Across Biomes, Species and Populations. Global Ecology and Biogeography, 33(12), e13921.

Boro, Pooja, and Bikram Singh. 2024. “Enhancement in Seed Germination through Pre-Sowing Treatments in Cinnamomum Glaucescens (Nees) Hand.-Mazz., A Native Tree of Eastern Himalaya, India”. Journal of Scientific Research and Reports 30 (9):928-35. <https://doi.org/10.9734/jsrr/2024/v30i92420>.

Chandra, R. J., Masilamani, P., Suthakar, B., Rajkumar, P., Sivakumar, S. D., & Manonmani, V. (2024). Seed Dormancy and After-ripening Mechanisms in Seed Germination: A Comprehensive Review. International Journal of Plant & Soil Science, 36(10), 68-92.