Techniques of Seed Priming and their Impact on Germination, Establishment and Vigour of Seeds

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ABSTRACT

Challenges related to inadequate seedling emergence and suboptimal stand establishment are prevalent in regions with low rainfall. Soil texture and structure management in semi-arid areas pose significant hurdles. Limited resources among small-scale farmers often hinder fine seedbed preparation, exposing them to greater risks compared to their more affluent counterparts. Conversely, achieving robust establishment enhances weed competitiveness, drought resilience, yield potential, and mitigates the need for costly re-sowing. Seed priming is widely recognized for its ability to enhance germination, expedite emergence, and improve stand establishment. This cost-effective and straightforward technique, if refined and promoted with farmer involvement, can substantially enhance livelihoods by boosting crop emergence rates, accelerating development, shortening crop cycles, and ultimately increasing productivity. Numerous studies attest to the importance of seed priming in achieving strong crop stands and optimal emergence. On-farm seed priming, particularly hydro-priming, shows promise for improving crop establishment across various tropical crops like sorghum, rice, maize, and pigeon pea. Additionally, seed priming can confer resistance to stresses such as drought and heat, offering further advantages in key field crops.

INTRODUCTION

Seed priming is a pre-sowing treatment technique that involves controlled hydration of seeds to initiate metabolic processes necessary for germination but does not allow the radicle to emerge. This technique is widely used to enhance seed performance, improve germination uniformity, and increase seedling vigour. The need for seed priming arises from various challenges faced during seed germination and seedling establishment, such as unfavourable environmental conditions, low soil moisture, and soil salinity.

The process of seed priming works by exposing seeds to a specific solution or water for a certain duration, allowing them to imbibe water and initiate metabolic processes like the breakdown of seed reserves, enzyme activation, and repair of deteriorated cellular components. However, the priming duration and conditions are carefully controlled to prevent the radicle from emerging, keeping the seeds in a pre-germination state. Once the priming process is complete, the seeds are dried back to their original moisture content before sowing.

Types of seed priming

1. **Hydro-priming:** This is the simplest form of seed priming, where seeds are soaked in water for a specific duration. Seeds undergo immersion in water at ideal temperature conditions, typically ranging between 5 to 20 °C. This soaking process may or may not involve aeration, an optional factor that can enhance germination under certain circumstances. Hydro-priming has been found to enhance germination rates, seedling emergence, and early seedling growth in various crops, including maize, rice, and pigeon pea. One of the advantages of hydro-priming is its cost-effectiveness and ease of application, making it suitable for resource-poor farmers.

2. **Halo-priming:** In this technique, seeds are soaked in solutions of inorganic salts, such as sodium chloride (NaCl), potassium nitrate (KNO_3), or calcium chloride ($CaCl_2$). Halo-priming has been shown to improve seed germination and seedling establishment under saline conditions. It can also promote early seedling growth and enhance final crop yield in salt-affected soils. For instance, rice seeds treated with a mixed salt solution exhibited faster germination under salt stress conditions (Chang-Zheng *et al*., 2002).

3. **Osmo-priming:** This technique involves soaking seeds in solutions with high osmotic potential, such as polyethylene glycol (PEG), glycerol, or mannitol, followed by drying before sowing. Osmo-priming has been reported to enhance germination rates, seedling vigour, and crop performance under both saline and non-saline conditions. In muskmelon, osmo-primed seeds showed increased activity of dehydrogenase and amylase enzymes, leading to improved germination. The presence of a semi-permeable outer layer found in certain seeds is the main structural feature influencing priming effectiveness (Pill,1995).

4. **Hormonal priming:** In this method, seeds are treated with plant growth regulators, such as gibberellic acid (GA_3), salicylic acid, or ethylene. Hormonal priming has been found to alleviate the adverse effects of various stresses, including salinity and drought, on seed germination and seedling growth. For example, wheat seeds soaked in ascorbic

acid, thiamine or sodium salicylate showed improved tolerance to salt stress during germination (Hamada and al-Hakimi, 2001).

5. **Biopriming:** Biopriming involves the integration of beneficial microorganisms or bioactive molecules into the priming mixture. This technique capitalizes on the symbiotic relationship between specific fungi or bacteria and plants, leading to enhanced plant growth, production of phytohormones, and improved resistance to both biotic and abiotic stresses. Commonly used strains for biopriming include those belonging to *Trichoderma spp*., *Enterobacter spp*., *Pseudomonas spp*., and *Bacillus spp*. Effective biopriming treatments have been achieved in various vegetable seeds, with strains like *Trichoderma harzianum* and *Bacillus spp.* showing promising results. Additionally, biopriming can involve the addition of secondary metabolites such as phytohormones (e.g., salicylic acid, abscisic acid, gibberellic acid), which regulate key biochemical processes during seed maturation, germination, and plant development. These treatments can be applied through liquid priming or solid matrix priming, offering a sustainable approach to enhancing seed vigor and crop performance.

6. **Chemo priming:** Chemo priming involves the addition of conventional disinfectants, natural substances, or agrochemicals to the priming solution to prevent microbial contaminations. Disinfectants like sodium hypochlorite and hydrochloric acid are commonly used to reduce losses in germination caused by pathogens, although careful consideration of parameters such as concentration, treatment duration, solution temperature, and seed age is necessary. Natural compounds with broad-spectrum antimicrobial activity, including organic acids, essential oils, and plant extracts, are preferred in organic agriculture. Fungicide-based products have also been tested for seed treatments, demonstrating improved seed vigor and emergence rates. Innovations in chemo priming technology focus on the development of environmentally friendly materials for seed treatment, such as pesticide-collagen hydrolysate mixtures and microencapsulated plant extracts, aiming to reduce pesticide dispersal and promote sustainable agricultural practices.

7. **Thermo priming:** Thermo priming, also known as seed treatment at different temperatures, has been shown to improve germination efficiency under adverse environmental conditions by reducing thermo-inhibition of seed germination. This technique involves pre-sowing seeds at different temperature regimes, with low temperatures generally yielding the best results. While thermo priming at high temperatures is less common, it can benefit plants adapted to warm climates. Studies have demonstrated slight improvements in seed development and germination rates, particularly in saline soil conditions. Combined with other treatments, thermo priming has shown beneficial effects on germination parameters in various plant species, contributing to improved nursery practices and commercial seedling production. Additionally, hydrotime analysis provides valuable insights into seed germination patterns and stress tolerance, supporting breeding programs by identifying plant lines with enhanced seed performance. Advances in automated seed imaging technology offer potential solutions to the time-consuming nature of hydrotime analysis, facilitating efficient

evaluation of seed germination under stressful conditions.

8. **Nano priming:** This technique involves the use of nanoparticles (NPs) during the pre-sowing treatment of seeds, which leads to a physiological change that enables seeds to germinate more efficiently. It is a more effective method compared to all other seed priming methods due to the unique properties such as their ability to develop electron exchange and enhanced surface reaction. The salient features of NP in seed priming include the formation of nanopores in the shoot, which helps in the uptake of water absorption, activation of reactive oxygen species (ROS)/antioxidant mechanisms in seeds, and the formation of hydroxyl radicals to loosen the walls of the cells and act as an inducer for rapid hydrolysis of starch. It also induces the expression of aquaporin genes that are involved in the intake of water and mediates H_2O_2 or ROS dispersed over biological membranes. Nano-priming induces starch degradation via the stimulation of amylase, which results in the stimulation of seed germination. It also induces a mild ROS that acts as a primary signaling cue for various signaling cascade events that participate in seed germination and breaking seed dormancy.

9. **Solid matrix priming:** Solid matrix priming, or 'matriconditioning,' serves as a cost-effective alternative to osmopriming, addressing concerns regarding the high costs and environmental impact associated with the latter. Osmopriming demands significant volumes of expensive osmotic solutions and intricate control systems for aeration and temperature, along with challenges in waste disposal. In contrast, solid matrix priming involves blending seeds with solid materials, such as organic or inorganic substances, to regulate moisture content and water uptake precisely. The choice of matrix is critical, requiring properties like inertness, non-toxicity, high water retention, and ease of removal post-treatment. Various natural substances like coal, sawdust, and vermiculite are commonly employed as matrices. This approach mimics the natural imbibition process in soil, achieving comparable results to liquid priming but at a reduced cost.

Pre-germinative metabolism

Pre-germinative metabolism, characterized by specific metabolic changes triggered during the transition from dry seed dormancy to active germination, plays a crucial role in seed priming. Upon water uptake, various cellular processes are initiated, including the synthesis of nucleic acids and proteins, ATP production, and activation of DNA repair and antioxidant mechanisms. These processes collectively contribute to what is termed 'pre-germinative metabolism'. Seed priming, a technique aimed at enhancing germination and seedling establishment, capitalizes on these metabolic dynamics.

Priming treatments induce controlled imbibition, leading to the activation of DNA repair pathways such as Base- and Nucleotide-Excision Repair (BER and NER), crucial for maintaining genome integrity. Additionally, transcription-coupled Nucleotide-Excision Repair (TC-NER) is activated to remove lesions from transcribed strands of active genes. The involvement of DNA helicases and microRNAs targeting helicases in DNA repair further emphasizes the importance of priming in preserving seed vigour.

Reactive oxygen species (ROS), pivotal in seed germination regulation, are managed through enhanced antioxidant enzyme activity during priming. Genes encoding antioxidant enzymes such as Superoxide Dismutase (SOD), Ascorbate Peroxidase (APX), Catalase (CAT), and Glutathione Reductase (GR) are upregulated, ensuring efficient ROS scavenging. Additionally, the induction of metallothionein (MT) genes highlights the role of ROS scavengers in seed protection and improved germination under stress conditions.

Seed priming treatments facilitate the activation of protective mechanisms essential for seed vigour and early seedling growth. By harnessing pre-germinative metabolism, priming enhances seed resilience to environmental stresses, promotes germination efficiency, and ultimately contributes to improved crop establishment and productivity.

Assessment of seed vigour using Digital Image Technology (DIT)

Seed technologists utilize digital image technology (DIT) as a non-invasive technique for accurately and automatically evaluating the morphological and physiological characteristics of seeds. This technology serves various purposes such as purity analysis, taxonomic screening, and vigor assessment (Dell'Aquila 2009). DIT tracks seed responses during imbibition, capturing the progression of seed enlargement until radicle emergence. This method enables high-resolution analysis of small seeds, measuring germination parameters such as speed and seedling length on an individual seed basis. Mathematical models analyze size and shape variations within seed populations. Images are acquired through devices like flat-bed scanners or CCD-cameras, and advanced algorithms extract numerical data for integration with biochemical and molecular findings. DIT-generated curves offer insights into seed responses under various conditions, including priming and environmental stress.

Advantages of Seed priming

1. **Enhanced hydration:** Seed priming ensures proper hydration, which results in enhanced activity of a-amylase that hydrolyses macro starch molecules into smaller and simple sugars. The availability of instant food to the germinating seed gives a vigorous start, as indicated by lower E50 and MET in treated seeds

2. **Faster production of germination:** Early emergence as indicated by lower E50 and MET in treated seeds may be due to the faster production of germination and better genetic repair, i.e., earlier and faster synthesis of DNA, RNA, and proteins.

3. **Improved nutrient uptake:** Seed priming with Zn improves productivity of chickpea and wheat, germination and early seedling growth of rice, development and root growth of maize seedling exposed to low root zone temperatures, and growth and nutrient status of cotton seedling under saline conditions.

4. **Starch degradation:** Nano-priming induces starch degradation via the stimulation of amylase, which results in the stimulation of seed germination.

5. **ROS/antioxidant mechanisms:** Nano-priming activates reactive oxygen species (ROS)/antioxidant mechanisms in seeds and forms hydroxyl radicals to loosen the walls of the cells and acts as an inducer for rapid hydrolysis of starch.

6. **Aquaporin genes**: Nano-priming induces the expression of aquaporin genes that are involved in the intake of water and also mediates H_2O_2, or ROS, dispersed over biological membranes.

7. **Seedling growth:** Seed priming enhances crop activity by stimulating the resistance of plants against abiotic and biotic stresses and improves seedling growth.

8. **Faster seedling establishment**: Primed seeds germinate and emerge from the soil more rapidly compared to non-primed seeds. This early establishment gives seedlings a head start, allowing them to outcompete weeds and better utilize available resources.

9. **Increased tolerance to environmental stresses**: Primed seeds exhibit enhanced tolerance to various abiotic stresses such as drought, salinity, and temperature extremes. This is due to physiological changes that occur during the priming process, including the accumulation of protective compounds and the activation of stress-related genes.

10. **Better seedling vigor**: Primed seeds produce more vigorous seedlings with improved root and shoot growth. This increased vigor leads to better establishment, faster growth, and ultimately higher crop yields.

11. **Reduced time to maturity**: As primed seeds germinate and establish quickly; the plants reach maturity earlier than non-primed counterparts. This can be advantageous in regions with short growing seasons or for crops with a long maturation period.

12. **Improved nutrient use efficiency:** Primed seeds have a better ability to mobilize and utilize seed reserves, leading to more efficient nutrient use and reduced dependence on external inputs.

13. **Increased crop uniformity**: Since primed seeds germinate and emerge more uniformly, the resulting crop stands are more even and consistent. This uniformity facilitates easier management practices and can lead to better product quality.

14. **Enhanced seed longevity**: The controlled hydration process during priming can improve seed longevity by breaking dormancy without allowing the seed to fully germinate. This can extend the shelf life of seeds, especially for species with short viability periods.

CONCLUSION

Seed priming offers numerous benefits that can significantly enhance crop production and agricultural sustainability. By improving germination rates, seedling vigor, and stress tolerance, primed seeds provide a head start for plants, leading to faster establishment, better resource utilization, and ultimately higher yields. Additionally, the technique promotes water conservation, nutrient use efficiency, and crop uniformity, making it an environmentally friendly and cost-effective approach. As agricultural challenges intensify due to climate change and population growth, seed priming emerges as a valuable tool for farmers and researchers to optimize crop performance and ensure food security in the face of adverse conditions.

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