AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 02, Issue: 08 (August, 2025)
Available online at http://www.agrimagazine.in

Enhancing Crop Performance through Seed Priming - Mechanisms and Applications

Shaik Hafiza Parveen, G. Prasanthi and *I. Sudhir Kumar
All India Coordinated Research Project on Maize, ANGRAU-ARS, Peddapuram, India
*Corresponding Author's email: i.sudhirkumar@angrau.ac.in

Seed priming plays a vital role in enhancing seed germination and seedling emergence. Insufficient seedling emergence and poor stand establishment are major constraints in crop production, often caused by biotic and abiotic stresses, as well as inadequate storage conditions. Various factors can limit seed germination and ultimately reduce crop yield. This review highlights the challenges associated with seed germination and plant growth, and discusses seed priming techniques that can synchronize germination, improve seed vigour, and lead to better crop establishment and yield. Seed priming stimulates key metabolic processes, helping to prevent seed deterioration, break dormancy, and induce systemic resistance against both biotic and abiotic stresses. The study explores various seed priming methods—such as hydro-priming, halo-priming, osmo-priming, matrix priming, hormone priming, nutri-priming, bio-priming, and nanoparticle priming used across different crops.

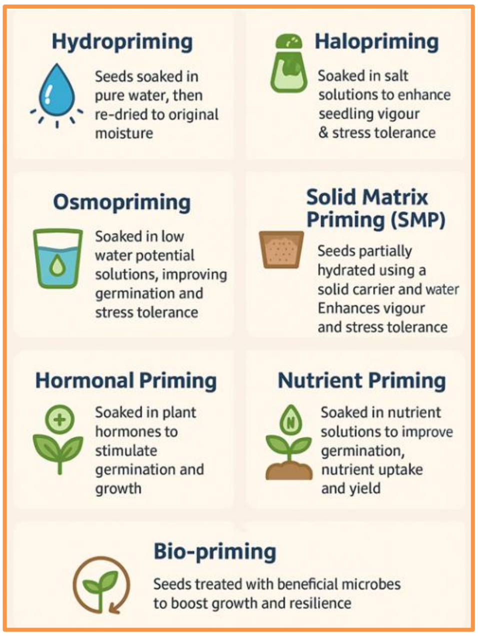
Keywords: Seed priming, Priming techniques, seed germination, crops establishment.

Introduction

Seed priming is a pre-sowing physiological seed enhancement technique that improves the speed, uniformity, and vigor of germination, leading to better stand establishment and higher crop productivity. The practice has historical roots; Theophrastus (372–287 BC) recognized that germination could be temporarily interrupted and recommended pre-soaking cucumber (*Cucumis sativus* L.) seeds in milk or water to promote earlier and more vigorous germination (Evenari, 1984). Similarly, Roman farmers practiced pre-hydration of legume seeds to accelerate and synchronize germination. The term *seed priming* was introduced by Heydecker in 1973, who demonstrated its efficacy in enhancing germination and emergence, particularly under stressful environmental conditions (Sivasubramaniam *et al.*, 2011). Since then, the technique has been extensively studied and applied to a range of crops, including maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), sweet corn (*Zea mays* var. *saccharata*), greengram (*Vigna radiata* L.), barley (*Hordeum vulgare* L.), lentil (*Lens culinaris* Medik.), and cucumber, with reported benefits such as improved crop establishment, early flowering, enhanced tolerance to abiotic stresses, and yield enhancement (Harris *et al.*, 2007; Sadeghian & Yavari, 2004).

Seed priming involves controlled hydration of seeds to a level that initiates pre-germination metabolic processes without visible radicle protrusion, followed by re-drying to near-original moisture content. This process activates metabolic pathways related to germination while preserving seed storability. As a simple, low-cost, and scalable approach, seed priming has been widely adopted in both research and commercial agriculture to mitigate the adverse effects of abiotic and biotic stresses, thereby contributing to sustainable crop production systems.

Major Seed Priming Techniques



Hydro-Priming: Hydro priming enables seeds to rapidly attain a specific moisture level while ensuring adequate oxygen supply, thereby stimulating the activity of enzymes responsible for energy production and the synthesis of metabolites essential for germination. The technique has been introduced in several Sub-Saharan African (SSA) countries as a practical strategy to mitigate environmental stresses, particularly drought, in rice cultivation. While some farmer-led trials have demonstrated its potential, further refinement is needed to address field-level challenges. Owing to its simplicity, low cost, and eco-friendly nature, hydropriming is particularly suitable for adoption by farmers in developing countries (Mabhaudhi & Modi, 2011).

Halopriming: Halopriming with controlled hydration regulates seed moisture and temperature during early germination stages, preventing radicle protrusion while initiating key biochemical activities. Halopriming prevents seed deterioration, breaks dormancy, and induces systemic resistance against various abiotic stresses by enhancing physiological attributes, functional biochemistry, and subcellular processes. Sodium chloride-based priming, for instance, has been shown to improve maize germination under stress by enhancing water imbibition, activating early metabolic pathways, increasing water use efficiency, and promoting higher germination rates compared to unprimed seeds (Chen *et al*., 2021; El-Sanatawy et al., 2021; Marthandan et al., 2020).

Osmopriming: Osmopriming involves controlled soaking of seeds in osmotic solutions under optimal aeration and temperature, followed by re-drying to original moisture content. This regulated hydration activates enzymatic and metabolic pathways associated with germination, improves stress tolerance, and enhances seedling vigour. PEG-based osmopriming is particularly effective under drought and salinity conditions, as it enhances antioxidant activity, promotes uniform seedling emergence, and improves water use efficiency (Basra *et al*., 2005). Specific salt-based osmopriming agents confer additional benefits: NaCl priming improves salt tolerance in maize (El-Sanatawy *et al*., 2021), KNO_3 priming enhances nitrate uptake and enzymatic activity (Harris *et al*., 2001), $CaCl_2$ priming stabilizes cell membranes via calcium-mediated signalling (Khan *et al*., 2009), and $MgSO_4$ or KCl priming supports ionic balance and osmotic stress tolerance (Jisha *et al*., 2013).

Solid matrix priming: The method, first described by Eastin (1990), involves mixing seeds with the solid matrix and water, allowing the seeds and matrix to compete for moisture until an equilibrium is reached. This simulates natural soil conditions, ensuring sufficient oxygen supply and preventing over-imbibition. SMP is effective in improving seed vigour, repairing aging seeds, breaking dormancy, and enhancing tolerance to environmental stresses (Nakkeeran *et al*., 2021) Compared to hydro- or osmopriming, SMP offers superior oxygen availability and allows the incorporation of beneficial additives such as fungicides or microbial inoculants. It uses minimal water, is cost-effective, and has been particularly successful in vegetable crops, where it promotes uniform emergence, robust seedling growth, and improved stress resilience (Sarthi & Rawat, 2020).

Hormonal priming: Hormonal priming with phytohormones regulates physiological and biochemical processes associated with germination and early seedling growth. Priming with IAA (e.g., 50 ppm) enhances root development, cell elongation, and vascular differentiation, while cytokinins stimulate both root and shoot growth, improving overall plant productivity (Zayed *et al*., 20170. Gibberellins promote enzyme activation, cell elongation, and rapid germination, particularly under salt stress (Ghodrat & Rousta, 2012). ABA application can enhance drought and heat tolerance (Farooq *et al*., 2006), and SA improves germination at sub-optimal temperatures (Afzal *et al*., 2006). Ethylene assists in breaking dormancy and initiating germination (Corbineau & Come, 1995), while BABA primes plants for improved defence responses to both biotic and abiotic stresses (Ton *et al*., 2005). By modulating hormonal signalling pathways, this technique enhances physiological readiness for germination and prepares seedlings for better performance under challenging environmental conditions.

Nutrient priming: Nutrient priming is a pre-sowing seed enhancement technique in which seeds are soaked in solutions containing essential macro- and micronutrients to improve germination, seedling vigour, nutrient uptake, and yield potential. This approach is particularly beneficial in nutrient-deficient soils, where early nutrient availability can enhance metabolic activity during germination. For example, $ZnSO_4$ priming has been shown to improve germination and early growth in chickpea and wheat under zinc-deficient conditions (Harris *et al*., 2007), while phosphate and molybdenum priming enhances nitrogen fixation and root development in legumes (Harris *et al*., 2001). Priming with Fe, Zn, and Mn has been reported to increase biomass and emergence rate in broadleaf plantain (Badiri *et al*., 2014). Additionally, $CuSO_4$ and $ZnSO_4$ priming can mitigate salinity-induced growth inhibition by improving ionic balance and osmotic adjustment (Iqbal *et al*., 2020). Nutrient priming has been associated with substantial yield gains in several regions for instance, maize yields in Asia have increased by up to 70% with appropriate nutrient priming protocols (Rahman *et al*., 2015). This low-cost, scalable method is especially valuable for smallholder farmers aiming to improve crop performance under resource-limited conditions.

Bio-priming: Bio-priming is an eco-friendly seed enhancement technique that integrates seed hydration with inoculation of beneficial microorganisms to improve germination, seedling vigour, and resilience to biotic and abiotic stresses. This method involves soaking seeds in water or nutrient solutions containing microbial inoculants such as plant growth-promoting rhizobacteria (PGPR), Trichoderma spp., Pseudomonas spp., Bacillus spp., and arbuscular mycorrhizal fungi (AMF)—followed by partial drying to restore near-original moisture content.Bio-priming enhances seedling establishment by improving nutrient solubilization (e.g., phosphorus, zinc, and iron), producing phytohormones (IAA, GA_3, cytokinins), and inducing systemic resistance against pathogens. For instance, *Trichoderma harzianum* bio-priming has been shown to protect maize seedlings from *Fusarium* wilt while promoting early root and shoot development. PGPR-based bio-priming enhances tolerance to drought and salinity by modulating osmolyte accumulation, antioxidant activity, and stress-responsive gene expression. Compared to chemical treatments, bio-priming offers a sustainable, low-cost solution that simultaneously improves germination, plant growth, and disease resistance, making it a valuable practice for integrated crop management systems.

Key benefits of seed priming

Priming Method	Priming Agents	Key Benefits
Hydro-priming	Pure water	Uniform and faster germination, improved stand establishment, low-cost, eco-friendly
Halo-priming	Aqueous salt solutions (KNO_3, KH_2PO_4, KCl, NaCl, $CaCl_2$, $Mg(NO_3)_2$, $ZnSO_4$, PEG, etc.)	Breaks dormancy, enhances stress tolerance, improves vigour, synchronizes germination
Osmopriming	Polyethylene glycol (PEG), mannitol, glycerol, other osmotic solutions	Improves germination under water deficit or salinity, enhances seedling vigour
Solid Matrix Priming	Moistened solid carriers (vermiculite, peat moss, sawdust)	Slow, uniform hydration, improved emergence, enhanced seedling growth

Priming Method	Priming Agents	Key Benefits
Hormonal Priming	Plant growth regulators (IAA, GA_3, CKs, ABA, SA, Ethylene, BABA)	Stimulates germination via hormonal regulation, improves stress resilience
Nutrient Priming	Macro- and micronutrients ($ZnSO_4$, Mo, B, P, Fe, Mn, $CuSO_4$)	Improves nutrient uptake, seedling vigour, yield, especially in nutrient-deficient soils
Bio-priming	Beneficial microbes (PGPR, *Trichoderma spp*., *Bacillus spp*.,)	Enhances nutrient solubilization, phytohormone production, and disease resistance

Advantages of priming

- Faster, uniform germination and better crop stands.
- Enhanced resilience to abiotic stresses (drought, salinity, heat).
- Improved nutrient uptake and early growth performance.

Future Prospects

Emerging techniques such as nano-priming, gamma irradiation, magnetic field, and UV priming show promise but require safety evaluation for environmental and health impacts. Sustainable, crop-specific, and eco-friendly approaches are essential for future adoption.

References

1. Badiri, M. T., Amiri, E., & Jowkar, A. (2014). The effect of nutrient priming on germination and seedling growth of broadleaf plantain (*Plantago major* L.). International Journal of Agriculture Innovations and Research, 2(5), 824–827.
2. Basra, S. M. A., Farooq, M., Tabassum, R., & Ahmad, N. (2005). Physiological and biochemical aspects of pre-sowing seed treatments in fine rice (*Oryza sativa* L.). Seed Science and Technology, 33(3), 623–628. https://doi.org/10.15258/sst.2005.33.3.09
3. Chen, X., Zhang, R., Xing, Y., Jiang, B., Li, B., Xu, X., Zhou, Y. (2021). The efficacy of different seed priming agents for promoting sorghum germination under salt stress. PLOS ONE 16(1): e0245505.
4. Eastin, J. A. (1990). Solid matrix priming of seed (U.S. Patent No. 4,911,307). U.S. Patent and Trademark Office.Effects of seed priming and water potential on germination of cotton (*Gossypium hirsutum* L.) and maize (*Zea mays* L.) in laboratory assays.
5. El-Sanatawy, A.M., Ash-Shormillesy, S.M.A.I., Qabil, N., Awad, M.F., Mansour, E. (2021). Seed halo-priming improves seedling vigor, grain yield, and water use efficiency of maize under varying irrigation regimes. Water 13: 2115.
6. Evenari, M. (1984). Seed physiology: From Theophrastus to the present. *Botanical Review*, 50(2), 119–142. https://doi.org/10.1007/BF02861071
7. Harris, D., Rashid, A., Hollington, P. A., Jasi, L., & Riches, C. (2007). Prospects of improving maize yields with 'on-farm' seed priming. *Field Crops Research*, 93(1), 24–32. https://doi.org/10.1016/j.fcr.2006.04.005
8. Harris, D., Rashid, A., Miraj, G., Arif, M. and Shah, H. (2007). On-farm seed priming with zinc sulphate solution, a cost-effective way to increase the maize yields of resource poor farmers. Field Crop Res. 110: 119-27.
9. Harriset al.,D. Harris, B.S. Raghuwanshi, J.S. Gangwar, S.C. Singh, K.D. Joshi, A. Rashi d, P.A. Hollington (2001). Participatory evaluation by farmers of 'on-farm' seed priming in wheat in India, Nepal and Pakistan.
10. Heydecker, W., Higgins, J., & Gulliver, R. L. (1973). Accelerated germination by osmotic seed treatment. *Nature*, 246, 42–44. https://doi.org/10.1038/246042a0.
11. Iqbal, S., Ali, I., Dilshad, M. I., Moatter, K., Ahmed, T., & Gilani, S. A. (2020). Influence of seed priming with $CuSO_4$ and $ZnSO_4$ on germination and seedling growth of oat (*Avena sativa* L.) under NaCl stress. Pure and Applied Biology, 9(9), 897–906.

12. Jisha, K. C., Vijayakumari, K., & Puthur, J. T. (2013). Seed priming for abiotic stress tolerance: an overview. Acta Physiologiae Plantarum, 35(5), 1381–1396.
13. Khan, A. A., Maguire, J. D., & Dewald, C. L. (2009). Osmotic priming, seed aging, and osmotic stress affect germination and seedling growth of *Leymus cinereus*. Seed Technology, 31(1), 28–3
14. Mabhaudhi T, Modi AT (2011) Can hydro-priming improve germination speed, vigour and emergence of maize landraces under water stress? J Agric Sci Technol B 1:20–28.
15. Marthandan, V., Geetha, R., Kumutha, K., Renganathan, V.G., Karthiyekan, A., Ramalingam, J. (2020). Seed priming: A feasible strategy to enhance drought tolerance in crop plants. International Journal of Molecular Sciences 21: 8258
16. Nakkeeran, S., T. Marimuthu, P. Renukadevi, S. Brindhadevi and S. Jogaiah (2021). Exploring the biogeographical diversity of Trichoderma for plant health. In Biocontrol Agents and Secondary Metabolites, Woodhead Publishing.
17. Rahman, M., Ahammad, K. U., & Ahmed, M. (2015). Effect of seed priming on maize (*Zea mays* L.) seedling emergence under different sowing dates. Bangladesh Journal of Agricultural Research, 39(4), 693–707.
18. Sadeghian, S. Y., & Yavari, N. (2004). Effect of water-deficit stress on germination and early seedling growth in sugar beet. *Journal of Agronomy and Crop Science*, 190(2), 138–144. https://doi.org/10.1046/j.1439-037X.2003.00080.x
19. Sarthi. and M. Rawat (2020). Effects of seed priming and it's duration on bitter gourd. Journal of Pharmacognosy and Phytochemistry, 9(6): 1950- 1953.
20. Sivasubramaniam, K., Gnanamurthy, S., & Rajendran, R. (2011). Effect of seed priming with micronutrients on germination and seedling vigour of maize (*Zea mays* L.). *Journal of Agricultural Technology*, 7(4), 1103–1112.
21. Zayed M, El-Kafafi E-S, Hafnawy S, El-Araby H (2017). Effect of auxin treatment on growth and physiological traits in two sunflower cultivars under saline conditions. J Plant Prod. 8:335–45.