# Bio-priming of seeds: There are More Ways to Avoid Pesticides

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**Abstract**

Seed bio-priming represents an emerging paradigm in sustainable agriculture, integrating seed hydration techniques with biological inoculation to enhance early seedling vigour, stress resilience, and pathogen resistance. Recent findings on seed priming and its evolution into bio-priming, explores different microbial and plant-derived agents employed, and critically evaluates its efficacy as a cost-effective and environmentally viable alternative to synthetic pesticides. Several bio priming agents significantly also enhance nutrient efficiency along with higher seed germination and reduction in pesticide use. The article highlights mechanisms of action, practical applications, and the expanding role of phytochemical-based bio-priming strategies.

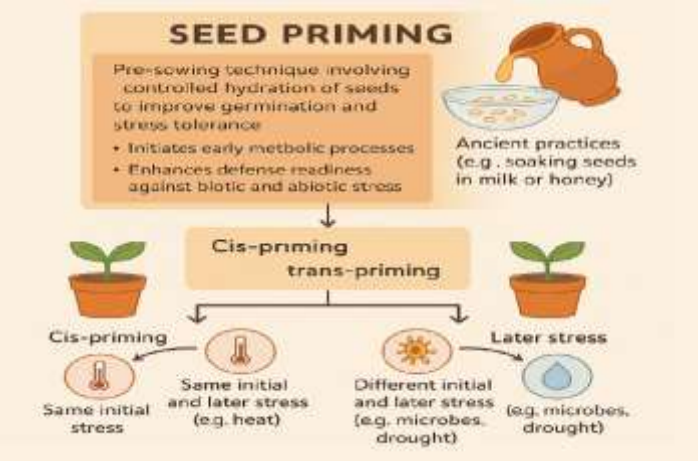
**Introduction**

The excessive reliance on chemical pesticides in modern agriculture has raised critical concerns regarding environmental safety, soil health, and human exposure risks. As regulatory pressure mounts and pest resistance escalates, there is an urgent need for ecologically sound alternatives. Seed priming—especially in its biologically augmented form, bio-priming—offers a viable approach by initiating plant defense mechanisms from the earliest stages of crop development. Bio-priming leverages beneficial microbes or plant-derived compounds during the pre-sowing hydration of seeds, fostering enhanced germination, plant vigor, and pathogen resistance, thus reducing the need for synthetic inputs.

**Seed Priming: Foundation for Bio-Priming**

Seed priming is a pre-sowing technique involving controlled hydration of seeds to initiate early metabolic processes, improving germination speed, uniformity, and plant stress tolerance. Ancient practices like soaking seeds in milk or honey laid the groundwork for modern priming methods, which gained scientific support in the 1960s (Cañizares et al. 2025). Various agents such as polyethylene glycol (PEG), salts, or beneficial microbes are used to trigger a "primed" physiological state. This enhances a plant's defense readiness against both biotic and abiotic stress. Priming can be classified into cis-priming, where the initial and later stressors are the same (e.g., heat or salt), and trans-priming, where different stimuli trigger cross-tolerance (e.g., microbes inducing drought resistance). This adaptive strategy enables plants to survive subsequent severe stress, making seed priming a cost-effective, eco-friendly approach in sustainable agriculture (Cañizares et al. 2025). Seed priming accelerates germination kinetics and uniformity (Yang et al. 2025). Conventional types include: Hydropriming (soaking seeds in water), Osmopriming (using osmotic solutions such as polyethylene glycol), Hormonal priming (application of phytohormones), and Chemical priming (utilization of protective chemicals, often with environmental drawbacks).

Bio-priming has emerged as an advanced iteration of this concept, enhancing physiological seed responses with biologically active agents that colonize the spermosphere and rhizosphere upon sowing.




**Bio-Priming: Concept and Mechanistic Insight:**

Bio-priming refers to the application of beneficial microbial consortia or bioactive plant-derived compounds during seed priming. These agents establish early rhizospheric interactions that trigger Induced Systemic Resistance (ISR), suppress pathogenic invasion, and stimulate root architecture and nutrient uptake.

***Microbial Bio-Priming***

Microbial agents used in bio-priming include:

*Plant Growth Promoting Rhizobacteria (PGPR)* - Such as *Bacillus subtilis*, *Pseudomonas fluorescens*, and

*Azospirillum spp.*, which enhance plant immunity via ISR, siderophore production, and phytohormone biosynthesis (Rajendran et al., 2019; Kaur and Pandove, 2025).

*Fungal antagonists* - Primarily *Trichoderma spp.*, exhibit mycoparasitism, competitive exclusion, and secretion of hydrolytic enzymes such as chitinases and glucanases (Reddy and Reddy, 2013).

*Arbuscular Mycorrhizal Fungi (AMF) and Phosphate-Solubilizing Microorganisms (PSM)* –Which improve nutrient acquisition and provide physical and biochemical barriers against pathogens (El-Beltagi et al. 2025).

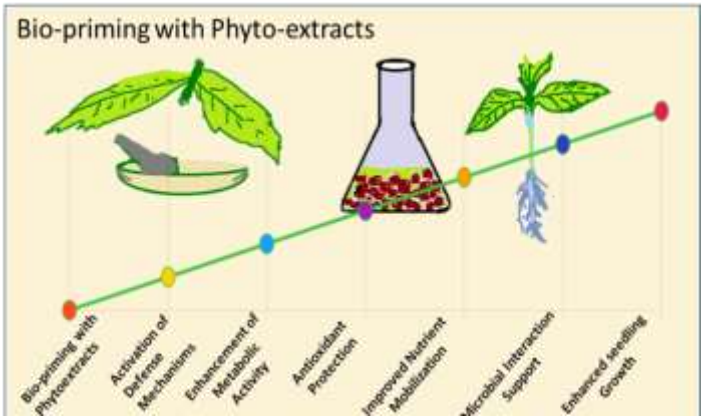
***Phytochemical-Based Bio-Priming: Phyto-priming***

Recent advancements highlight the application of plant extracts rich in antimicrobial and allelopathic compounds as priming agents (Ben-Jabeur et al., 2023; Farooq et al., 2024). Extracts from *Azadirachta indica* (neem), *Moringa oleifera*, *Allium sativum* (garlic), and *Zingiber officinale* (ginger) *etc* demonstrate antifungal, antioxidant, and growth-stimulating properties. These botanicals are particularly attractive for small-scale and organic farming systems due to their accessibility and safety.

**Mode of Action**

Bio-priming involves multiple synergistic mechanisms:

- **Colonization of Seed Surface and Rhizosphere**: Beneficial microbes adhere and proliferate on the seed coat, transitioning to the rhizosphere post-germination.
- **Biocontrol Activity**: Microbial antagonists secrete antifungal compounds (e.g., iturins, fengycins) and enzymes that degrade pathogen cell walls.
- **Induction of Defense Pathways**: ISR pathways, often involving salicylic acid or jasmonate signaling, are activated in host plants.
- **Enhanced Nutrient Solubilization**: Phosphate solubilization, nitrogen fixation, and siderophore-mediated iron chelation improve plant nutrition.
- **Phytohormonal Modulation**: Bio-priming alters levels of indole acetic acid (IAA), gibberellins, and cytokinins, enhancing root and shoot development.




**Advantages over Conventional Pesticide Use**

Empirical studies across diverse agroecosystems validate the effectiveness of bio-priming. In rice, *Trichoderma asperellum* priming has reduced sheath blight incidence and improved seedling vigor (de Sousa, 2020). Maize bio-primed with *Pseudomonas fluorescens* displayed enhanced root biomass and reduced Fusarium root rot (Reddy and Reddy, 2013). Tomato seeds treated with *Bacillus thuringiensis* exhibited reduced severity of *Fusarium oxysporum* wilt and greater early growth performance (Dehkian, et al., 2024). Wheat seeds bio-primed with microbial consortia including PSM and PGPR have demonstrated improvements in phosphorus acquisition and suppression of stripe rust (Mondal et al. 2022; Ben-Jabeur et al. 2023).

The key benefits of bio-priming include (Reddy and Reddy 2013, Yang et al. 2025; Kaur and Pandove, 2025; Shil et al., 2025)**:**

**Eco-Safety**: Eliminates pesticide residues and minimizes non-target organism impacts.

- **Cost-Effectiveness**: Seed treatment requires minimal inoculum quantities (often 10–50 g per kg seed), making it feasible for smallholders.
- **Sustainability**: Builds long-term soil health and rhizosphere biodiversity.
- **Systemic Resistance**: Enhances internal plant immunity, reducing recurrent pesticide applications.
- **Abiotic Stress Tolerance**: Bio-priming with *Azospirillum* or *Trichoderma* spp. improves tolerance to drought and salinity through osmolyte regulation and antioxidant enzyme activity.

**Limitations and Future Directions**

***Shelf-Life Constraints:*** Microbial viability on seeds declines under poor storage conditions.

***Environmental Variability:*** Performance may vary with soil microbiota, moisture, and temperature.

***Strain Specificity:*** Bio-efficacy is often strain- and crop-specific, necessitating tailored formulations.

Future research should prioritize the development of microbial consortia with broad-spectrum efficacy, nano-formulated bio-priming agents, and standardized protocols for integration into certified organic systems.

**Conclusion**

Bio-priming stands at the intersection of microbial biotechnology and sustainable crop management. By fortifying seeds with beneficial microorganisms or phytochemical agents, it offers a robust, low-cost, and environmentally responsible alternative to pesticide-dependent agriculture. With advancing research and field validation, bio-priming could become a cornerstone in climate-resilient and regenerative agriculture systems.

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