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Enhancing Germination and Establishment of Cereals Through Chemical Priming

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Abstract: Seed priming, a pre-sowing treatment, enhances germination and seedling establishment in various crops, particularly cereals. This review examines the role of chemical priming agents in modulating germination responses in cereal crops. We explore the physiological and biochemical mechanisms involved, focusing on how specific chemical compounds improve germination rate, uniformity, and stress tolerance. The impact of chemical priming on crop establishment under both optimal and adverse environmental conditions is discussed, along with its implications for agricultural productivity.

Keywords: Cereal crops, seed priming, chemical priming, germination enhancement, seedling vigor, crop establishment, abiotic stress tolerance, agricultural productivity, sustainable agriculture, seed treatment technologies.

Introduction: Cereal crops (e.g., wheat, rice, maize) are fundamental to global food security. Achieving optimal crop establishment, defined as the successful emergence and development of seedlings, is crucial for maximizing yield potential. However, various factors, including suboptimal soil conditions, water stress, and salinity, can hinder seed germination and early seedling growth. Seed priming, a pre-sowing treatment that involves controlled hydration and dehydration, has emerged as a valuable technique to improve

germination performance and enhance crop establishment (Ashraf & Foolad, 2005; Bewley et al., 2013; Copeland & McDonald, 2012).

Chemical priming, a specific type of seed priming, utilizes various inorganic or organic compounds to trigger pre-germinative metabolic activities without radicle protrusion. This review focuses on the role of chemical priming agents in modulating germination responses in cereal crops. It examines the mechanisms by which these agents enhance germination rate, uniformity, and stress tolerance, ultimately leading to improved crop establishment.

Cereal crops, including wheat (Triticum aestivum), rice (Oryza sativa), maize (Zea mays), barley (Hordeum vulgare), and sorghum (Sorghum bicolor), form the cornerstone of global food production, contributing to more than half of the caloric intake for the human population. Ensuring the successful establishment of these crops is vital not only for maximizing agricultural productivity but also for achieving global food security, especially in the face of climate change, population growth, and diminishing arable land resources.

Seed germination and seedling emergence represent the first and most vulnerable stages in the life cycle of cereal crops. Poor germination and uneven seedling establishment can significantly reduce plant stand density, leading to substantial yield losses. Various abiotic stresses—including drought, salinity, low and high temperature extremes, and soil-borne diseases—commonly impair seed germination and early growth, posing a major challenge to farmers worldwide. Traditional agronomic practices, such as adjusting planting dates or irrigation regimes, are often insufficient to mitigate these early-stage vulnerabilities, prompting the need for innovative solutions at the seed level.

One promising approach that has emerged over recent decades is seed priming—a controlled hydration technique that initiates pre-germinative metabolic processes without completing germination. Among the various types of priming, chemical seed priming involves the soaking of seeds in solutions containing chemical agents that can enhance seed vigor, metabolic activity, and stress tolerance. Unlike simple water priming (hydropriming), chemical priming introduces bioactive substances that can modulate physiological and biochemical pathways, giving the seed a significant advantage upon sowing.

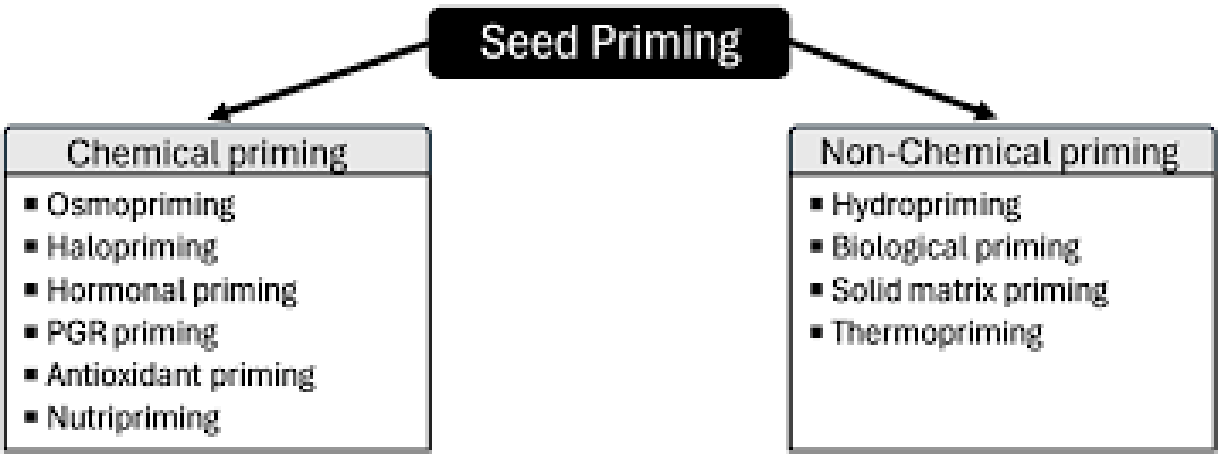

Figure 1. List of chemical and non-chemical seed priming methods.

The mechanisms by which chemical priming enhances seed performance are multifaceted. Primed seeds often exhibit faster water uptake, improved mobilization of stored food reserves, enhanced antioxidant defense systems, and better hormonal balance, all of which contribute to faster and more uniform germination. Moreover, priming can "condition" seeds to tolerate adverse environmental conditions, effectively acting as a pre-sowing stress-hardening treatment. Agents commonly used for chemical priming include potassium nitrate (KNO_3), calcium chloride ($CaCl_2$), gibberellic acid (GA_3), hydrogen peroxide (H_2O_2), and polyethylene glycol (PEG), each offering specific physiological benefits.

Despite its advantages, the adoption of chemical seed priming remains limited in large-scale cereal farming due to factors such as lack of standardized protocols, concerns over chemical residues, and varying effectiveness depending on crop genotype and environmental context. Therefore, further research and field validation are critical to refine priming techniques, identify crop-specific optimal treatments, and integrate priming into sustainable farming practices.

In this article, we comprehensively review the role of chemical seed priming in enhancing cereal crop establishment. We focus on the mechanisms of action, effectiveness across different cereal species, physiological and biochemical changes induced by priming agents, and the challenges and future prospects of this promising technology.

METHODS

This review synthesizes findings from studies investigating the effects of chemical priming on cereal seed germination and seedling establishment. The search strategy involved a systematic review of scientific literature using databases. Key search terms included "seed priming," "chemical priming," "cereal crops," "germination," "seedling establishment," "stress tolerance," and specific chemical agents (e.g., "potassium nitrate," "salicylic acid").

The review focuses on studies that:

- Examined the effects of chemical priming on cereal crops (wheat, rice, maize, etc.).
- Investigated the physiological and biochemical mechanisms underlying priming-induced improvements.
- Evaluated the impact of chemical priming under both optimal and stress conditions.

Results

Chemical priming has been shown to improve cereal seed germination and seedling establishment through several mechanisms:

- Enhanced enzyme activity: Priming activates enzymes involved in carbohydrate metabolism, leading to faster mobilization of seed reserves (Aghbolaghi & Sedghi, 2014; Varier et al., 2010).
- Increased antioxidant capacity: Chemical priming can enhance the levels of antioxidant enzymes, protecting seedlings from oxidative stress (Jamal et al., 2011; Mazhar et al., 2022).
- Improved osmotic adjustment: Some priming agents facilitate osmotic adjustment, enabling seeds to germinate under water stress or saline conditions (Bakht et al., 2011; Tavili et al., 2011).
- Hormonal modulation: Priming can influence the levels of plant hormones like abscisic acid and gibberellins, promoting germination (Abiri et al. 2016).

Specific chemical agents and their effects:

- Potassium nitrate (KNO3): Improves germination rate and uniformity in rice (Ruttanaruangboworn et al., 2017).
- Salicylic acid: Enhances stress tolerance and seedling vigor in wheat (Salehzade et al., 2009).
- Moringa leaf extract: Improves germination of maize seeds (Afzal et al., 2012; Basra et al., 2011).
- Calcium oxide nanoparticles: Improves germination under drought stress (Mazhar et al., 2022)

Priming enhances germination under both normal and stress conditions, including drought (Aryal et al., 2018; Asaduzzaman et al., 2021), salinity (Aymen & Cherif, 2013; Jafar et al., 2012; Mahara et al. 2022), and low temperature (Afzal et al., 2008).

DISCUSSION

The reviewed studies demonstrate that chemical seed priming is an effective strategy for improving germination and seedling establishment in cereal crops. By modulating key physiological and biochemical processes, chemical priming agents enhance germination rate, uniformity, and stress tolerance.

The benefits of chemical priming translate to improved crop establishment, particularly under adverse environmental conditions. This can lead to:

- Increased seedling vigor: Primed seeds produce more robust seedlings with enhanced growth potential (Anwar et al., 2021; Mim et al. 2021).
- Uniform emergence: Synchronized emergence improves crop management and resource utilization.
- Higher yield potential: Improved crop establishment contributes to increased grain yield (Farooq et al., 2006, 2007; Mahajan et al., 2011; Singh et al. 2023).
- Enhanced stress tolerance: Priming can mitigate the negative effects of environmental stresses, stabilizing yield under fluctuating conditions.

Chemical priming is relatively simple, cost-effective, and can be easily adopted by farmers (Harris et al., 2016; Musa et al. 1999; Raj & Raj, 2019). Further research should focus on optimizing priming protocols for specific cereal varieties and environmental conditions, as well as exploring novel priming agents and delivery methods (Ejaz et al., 2019; Sarfraz et al., 2019; Waqas et al. 2019; Zulfiqar, 2021).

CONCLUSION

Chemical seed priming is a valuable tool for enhancing germination and seedling establishment in cereal crops. By improving germination rate, uniformity, and stress tolerance, chemical priming contributes to improved crop establishment and ultimately, increased agricultural productivity.

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