AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 02, Issue: 07 (July, 2025)
Available online at http://www.agrimagazine.in

Sodium Nitroprusside: A Key Element to Enhance Seed Germination and Abiotic Stress Tolerance

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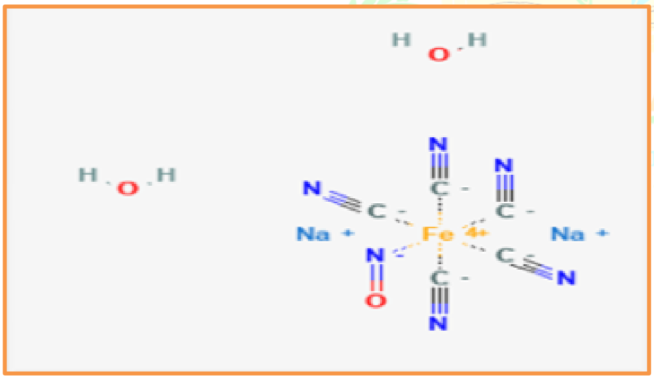
Seed germination is crucial for crop establishment but is often hindered by stresses like salinity, drought, and extreme temperatures due to oxidative damage and hormonal imbalance. Seed priming with sodium nitroprusside (SNP), a nitric oxide donor, offers a cost-effective solution by enhancing respiration, cell signaling, and ion balance. This leads to faster, more uniform germination, improved seedling vigor, and better stress tolerance, positioning SNP as a valuable biostimulant for climate-resilient agriculture. Sodium nitroprusside (SNP) a potent nitric oxide (NO) donor has attracted considerable interest for its ability to enhance germination and seedling vigour, particularly under abiotic stress. It is a red-colored, water-soluble salt with the chemical formula $C_5H_4FeN_6Na_2O_3$, composed of a ferrous iron center complexed with nitric oxide (NO) and five cyanide ligands. It is light-sensitive and belongs to a class of compounds known as vasodilators. Nitric oxide (NO) is a small, gaseous signalling molecule known to regulate several plant functions, including seed dormancy release, phytohormone balance, antioxidant defence activation, and protection of cellular membranes. As a source of NO in aqueous environments, SNP has demonstrated promising results in improving germination rates and stress tolerance across a range of crop species (Guo *et al*., 2003).

Key words: Sodium nitroprusside, Abiotic stress



Mechanism of Action

Upon application, SNP releases nitric oxide, which interacts with multiple cellular targets and signaling pathways. One of its primary functions during germination is to modulate hormone signaling, particularly by downregulating abscisic acid (ABA) a germination-inhibiting hormone and upregulating gibberellic acid (GA), which promotes radicle protrusion and enzymatic mobilization of stored food reserves. Furthermore, NO induces the expression and activity of antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD). These enzymes scavenge harmful reactive oxygen species (ROS), which accumulate during seed imbibition and metabolic reactivation. By reducing ROS-induced damage to lipids, proteins, and DNA, SNP helps maintain membrane integrity and cell viability during germination.

Additionally, NO is known to interact with signaling molecules such as calcium ions (Ca^{2+}) and cyclic GMP (cGMP), enhancing signal transduction pathways associated with seed metabolism and stress response. These interactions collectively contribute to faster, more synchronized germination, even under suboptimal environmental conditions.

Role of Sodium Nitroprusside (SNP) in Germination, Dormancy and Abiotic Stress

1. Germination and Seedling Vigour

SNP up-regulates germination responsive genes and proteins in cereals and legumes, boosting radicle emergence and seedling vigour even under salinity or drought (Sen, 2010). By modulating antioxidant enzymes (SOD, POD, CAT) and reducing total phenolics, SNP priming enhances metabolic function during imbibition. In soybean "half-seed" explants, 30 µM SNP plus cytokinin increased shoot regeneration from 76% to 91%, while 50 µM SNP under salt stress stabilized Na^+/K^+ ratios, minimized tissue browning, and elevated SOD/CAT activities—demonstrating improved tolerance and developmental rates. (Liu and Guo., 2013).

Key Biochemical Shifts

- ↑ α-Amylase & β-Amylase → enhanced starch degradation & sugar availability
- ↑ Protease activity → improved nitrogen mobilization
- ↑ Antioxidant capacity → efficient ROS scavenging

2. Dormancy Breaking

NO donors reverse physiological dormancy by rebalancing germination stimulators or inhibitors across diverse species (apple, Amaranthus, Arabidopsis, barley). SNP triggers rapid ABA catabolism via up-regulation of CYP707A2 (ABA 8′-hydroxylase) and down-regulation of NCED, reducing ABA levels and sensitivity (Bethke *et al.*, 2006). This gene hormone interaction in the endosperm during early imbibition is critical for dormancy release.

3. Salt Stress Alleviation

Excess Na^+/Cl^- induces osmotic imbalance, ROS accumulation (H_2O_2), membrane peroxidation (MDA), and chlorophyll degradation (Zheng *et al.*, 2009)

Exogenous SNP reverses these effects by:

- Maintaining RWC & MSI → preserves turgor and biomass
- Stabilizing ionic homeostasis → Na^+/K^+ ratio balance
- Enhancing chlorophyll content → protects photosynthetic machinery
- Up-regulating SOD, APX, POD → synergistic ROS scavenging

4. Drought Stress Mitigation

Water deficit triggers ABA-mediated stomatal closure and osmolyte synthesis. SNP elevates NO in guard cells to reorganize actin, regulate vacuole dynamics, and facilitate stomatal movement. Key drought-related effects include:

- Reduced transpiration and membrane injury
- Improved hydration via osmolytes (proline) and aquaporins
- LOX inhibition → limits lipid peroxidation
- Crosstalk with JA/MeJA pathways → coordinates systemic drought responses

5. Heat Stress Protection

High temperatures generate ROS (O_2^-, H_2O_2, •OH) and methylglyoxal (MG), impairing membranes, pigments, and enzymes. SNP confers thermotolerance by:

- Scavenging ROS directly and via ↑ antioxidant enzymes
- Up-regulating heat-responsive genes and glyoxalase system (MG detoxification)
- Stabilizing chlorophyll and photosynthetic rates.

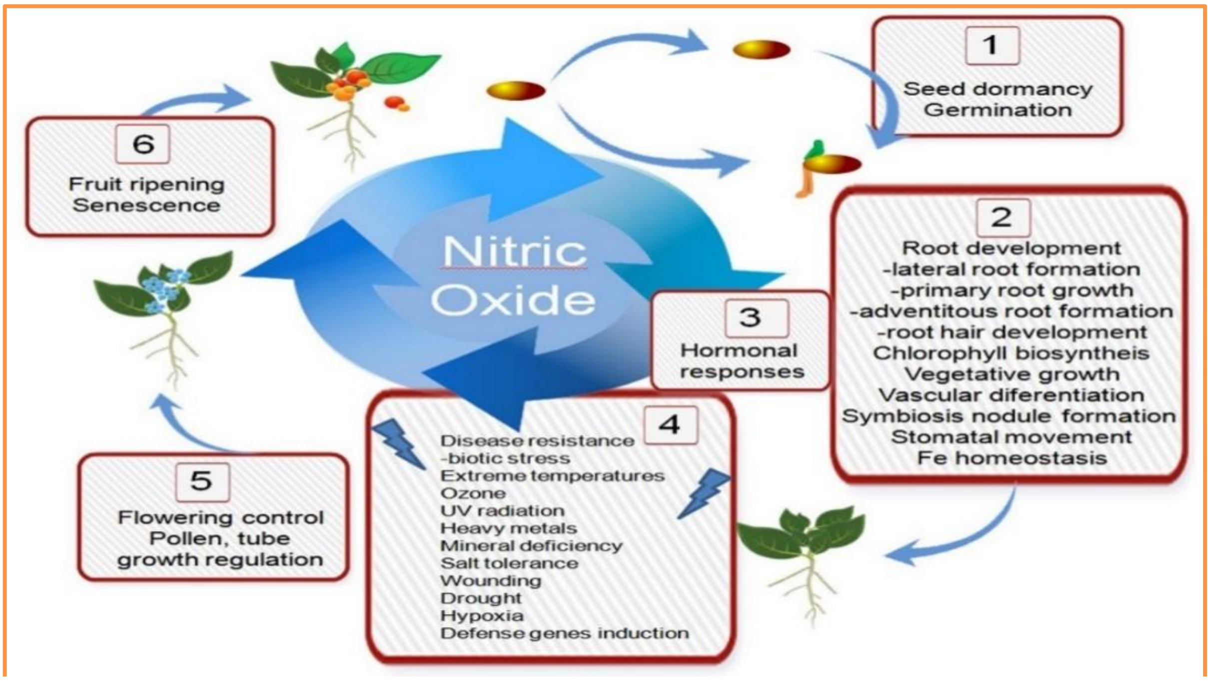


Fig 1. Application of Nitric oxide

Conclusion and Future Prospects

Sodium nitroprusside has emerged as a powerful tool in seed enhancement strategies, especially in the context of climate resilient agriculture. Its capacity to modulate hormonal pathways, enhance antioxidant defence, and improve metabolic efficiency provides a strong foundation for its application in seed priming and pre-sowing treatments. However, challenges remain regarding its optimal concentration, treatment duration, and potential phytotoxic effects at higher doses. Moreover, crop-specific responses to SNP need to be systematically studied under field conditions. Future research should focus on integrating SNP-based seed priming with other bio-stimulants and precision farming practices to maximize crop establishment and yield under stress-prone environments.

References

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