Sustainable Agriculture through Multidisciplinary Seed Nanopriming: Prospects of Opportunities and Challenges

Ajay Vikram Singh

German Federal Institute for Risk Assessment (BfR)

Email ajay-vikram.singh@bfr.bund.de

Phone. +49-1732624116

Outline of the Presentation

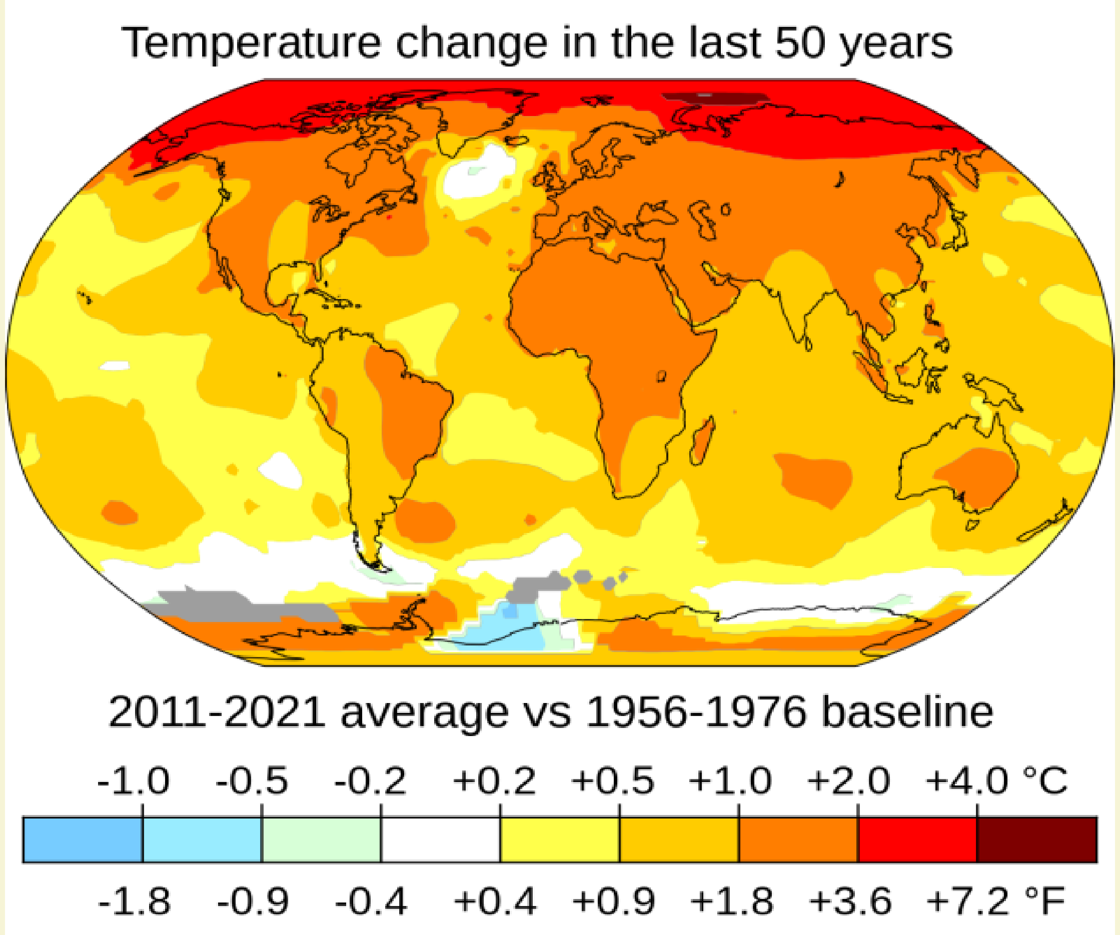
- ✓ Introduction of Seed Nanopriming Technology
- ✓ Molecular Targets of Seed Nanopriming
- ✓ Effect of Nanopriming under Abiotic-Biotic Conditions
- ✓ Effect of Combined Seed Priming Treatment of Nanomaterials with Microbes
- ✓ Effect of Combined Seed Priming Treatment of Nanoparticles and Cold Plasma Technology
- ✓ Artificial Intelligence and Machine Learning Technology for Nanoprimed Seed Diagnostics
- ✓ Limitations of Nanopriming Techniques and Future Prospects

Why Seed Nanopriming Technology?

There are worrying global trends in **malnutrition**.

The way food is produced, distributed and consumed worldwide has also changed dramatically.

This vastly different world calls for new ways of thinking about **hunger and food insecurity**.

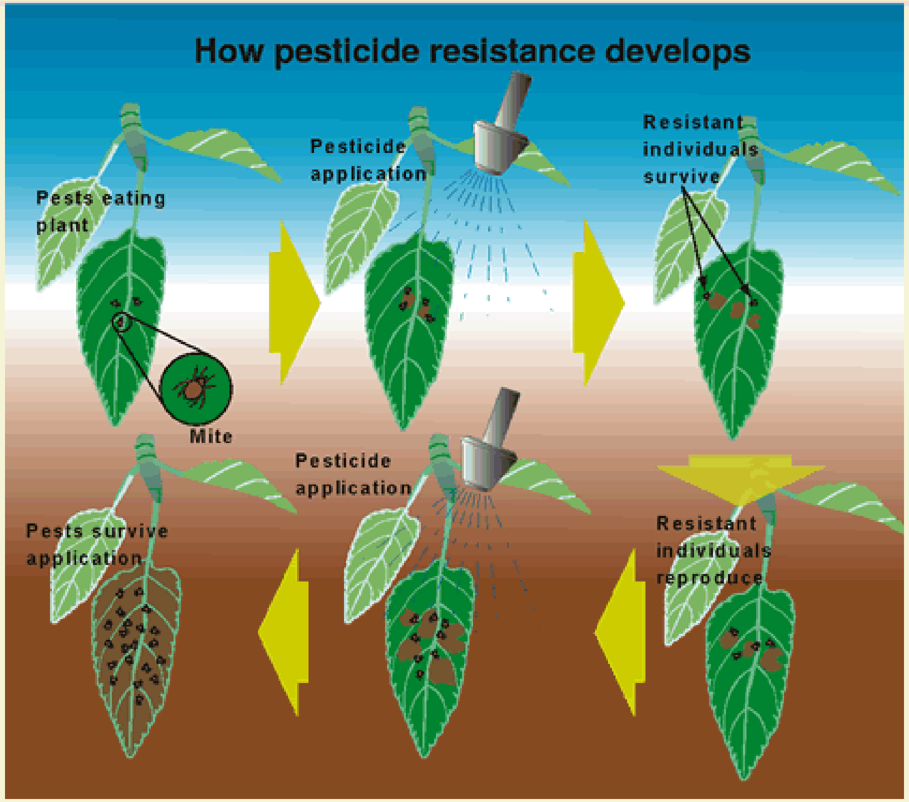


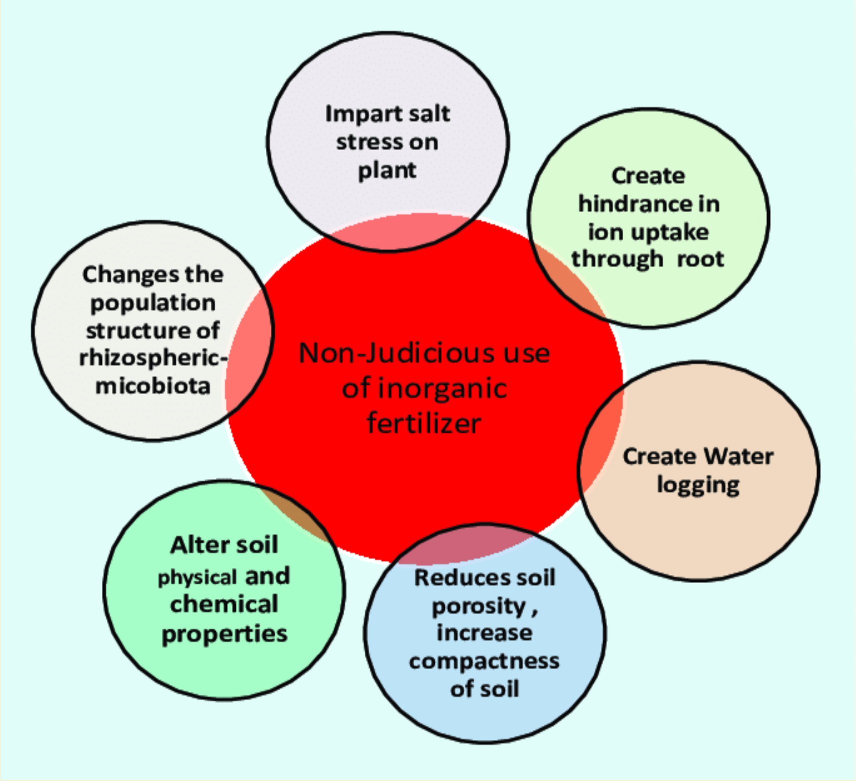
Drought stress influence **seed germination** and seedling **growth** of many plants. **Seed** priming could be used to alleviate the depressive effects.

Food and agriculture organization of united nations

Guzzon, F., et al. "Drought avoidance adaptive traits in seed germination and seedling growth of Citrullus amarus landraces." *South African Journal of Botany* 113 (2017): 382-388.

Why Seed Nanopriming Technology?





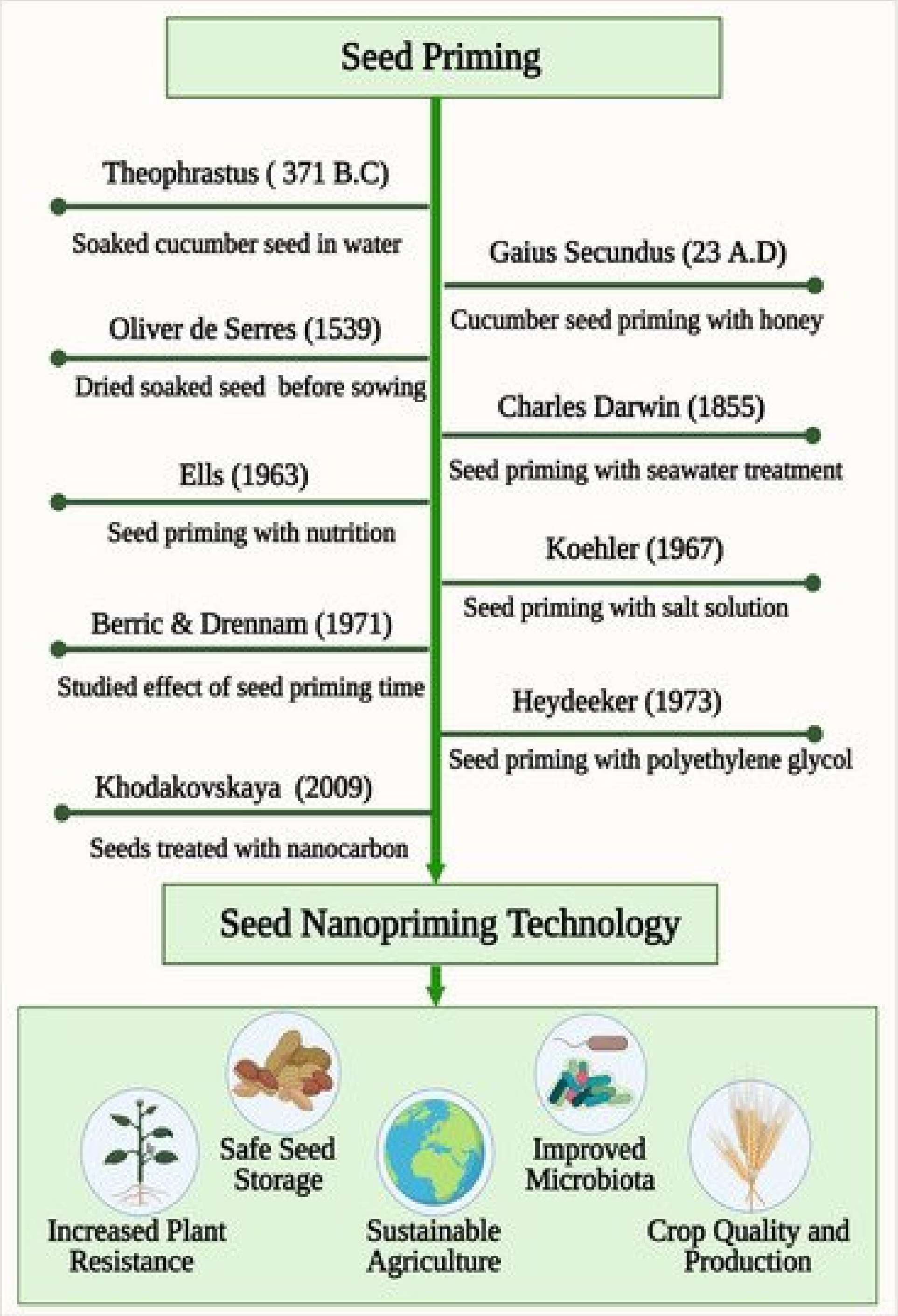
When a pesticide is first used, a small proportion of the pest population may survive exposure to the material due to their distinct genetic makeup.

These individuals pass along the **genes for resistance to the next generation.**

Experiments conducted by Indian Council of Agricultural Research (ICAR) indicated that non-judicious and imbalanced use of inorganic fertilizers (NPK) over years **may result in deterioration of soil fertility/ nutrient deficiencies which leads to crop production**.

https://www.canr.msu.edu

https://www.indiainfoline.com/



Introduction of Seed Nanopriming Technology

Theophrastus, (371–287 B.C.) who, observed during an investigation that soaking cucumber seeds in water causes their germination.

Cucumber seeds in honey and water for seed germination was reported by the Roman naturalist Gaius Plinius Secundus (23–79 A.D.)

Oliver de Serres, in 1539–1619, found that soaking seeds in manure water for 2 days and drying them prior to sowing was an effective cure for poor crop growth.

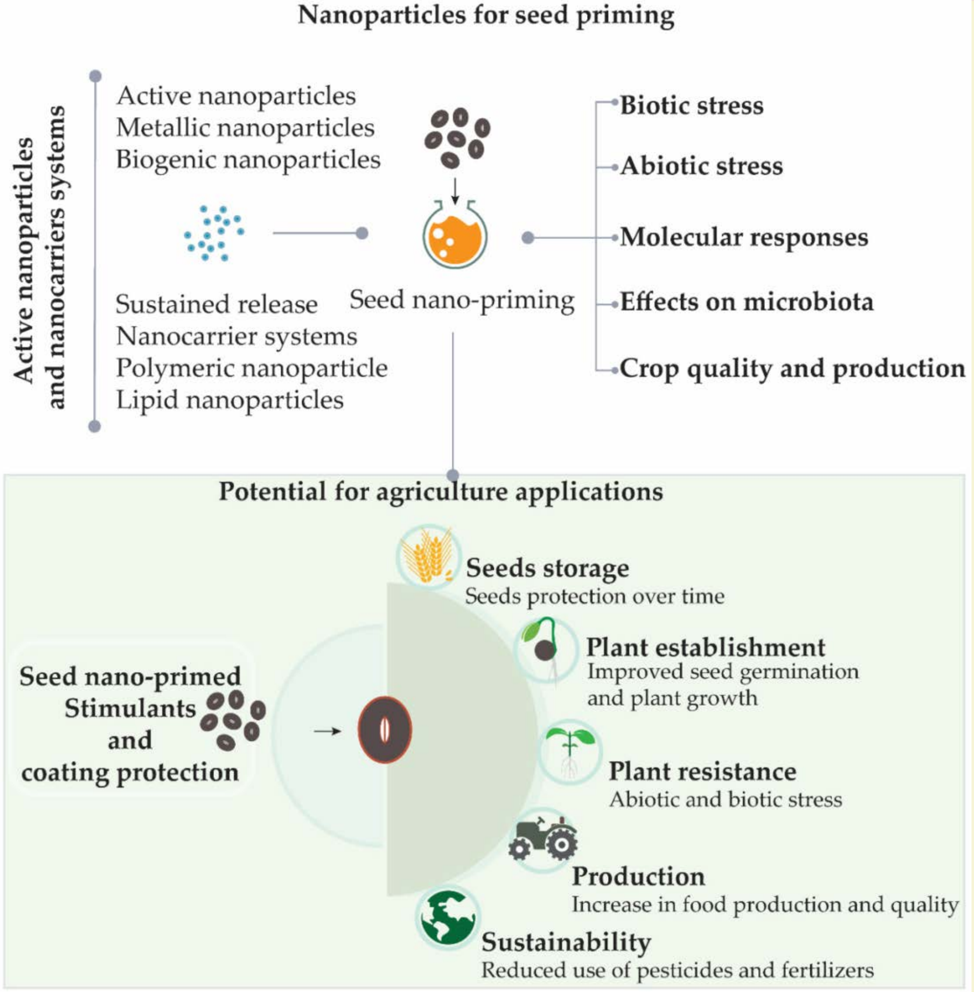
The osmo-priming process was tested on lettuce and cress seeds in seawater by Charles Darwin, who observed that the primed seeds germination.

Ells (1963) presented the modern concept of seed priming. His experiments with nutrient solutions showed a high germination rate.

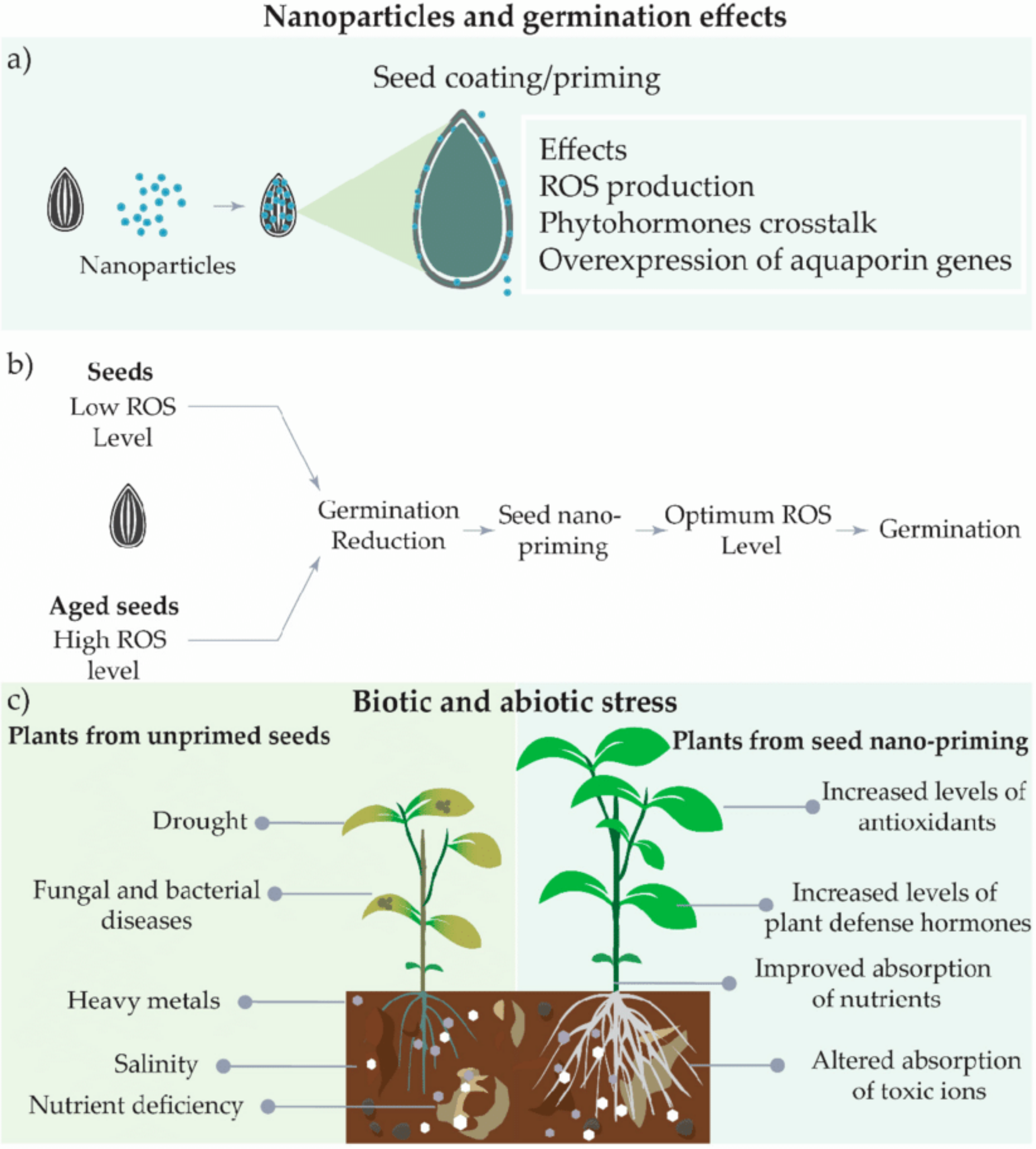
Khodakovskaya et al. published one of the first studies to demonstrate the potential for nanomaterials to affect seed germination.

Shelar, Amruta, et al. "Sustainable Agriculture through Multidisciplinary Seed Nanopriming: Prospects of Opportunities and Challenges." *Cells. (2021) MDPI*

Introduction of Seed Nanopriming Technology



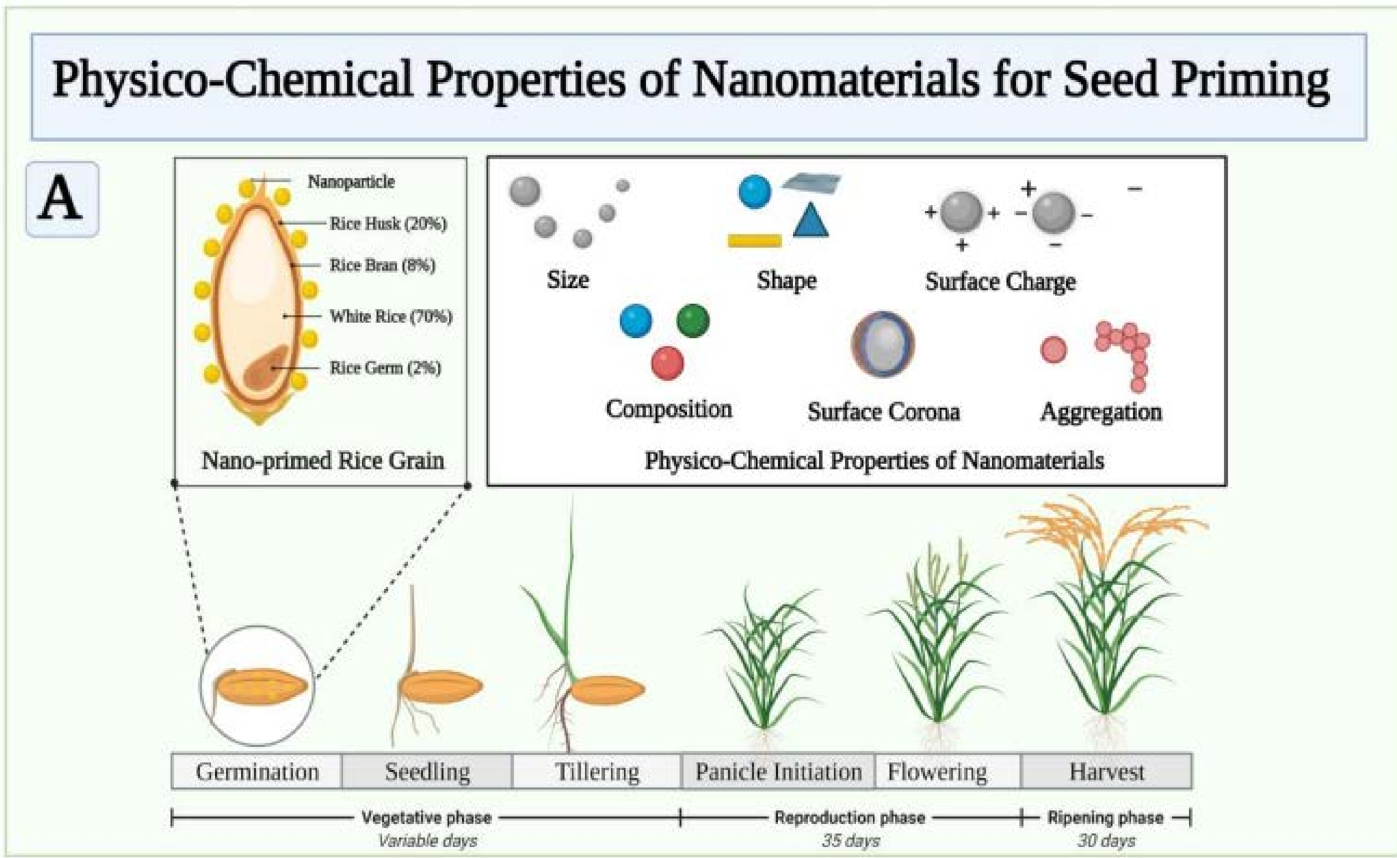
Effects of seed nano-priming on seeds and plants under abiotic and biotic stresses. (a) Effects of seed nanopriming during the germination, (b) effects of seed nano-priming on ROS levels, and (c) potential effects under biotic and abiotic stresses.



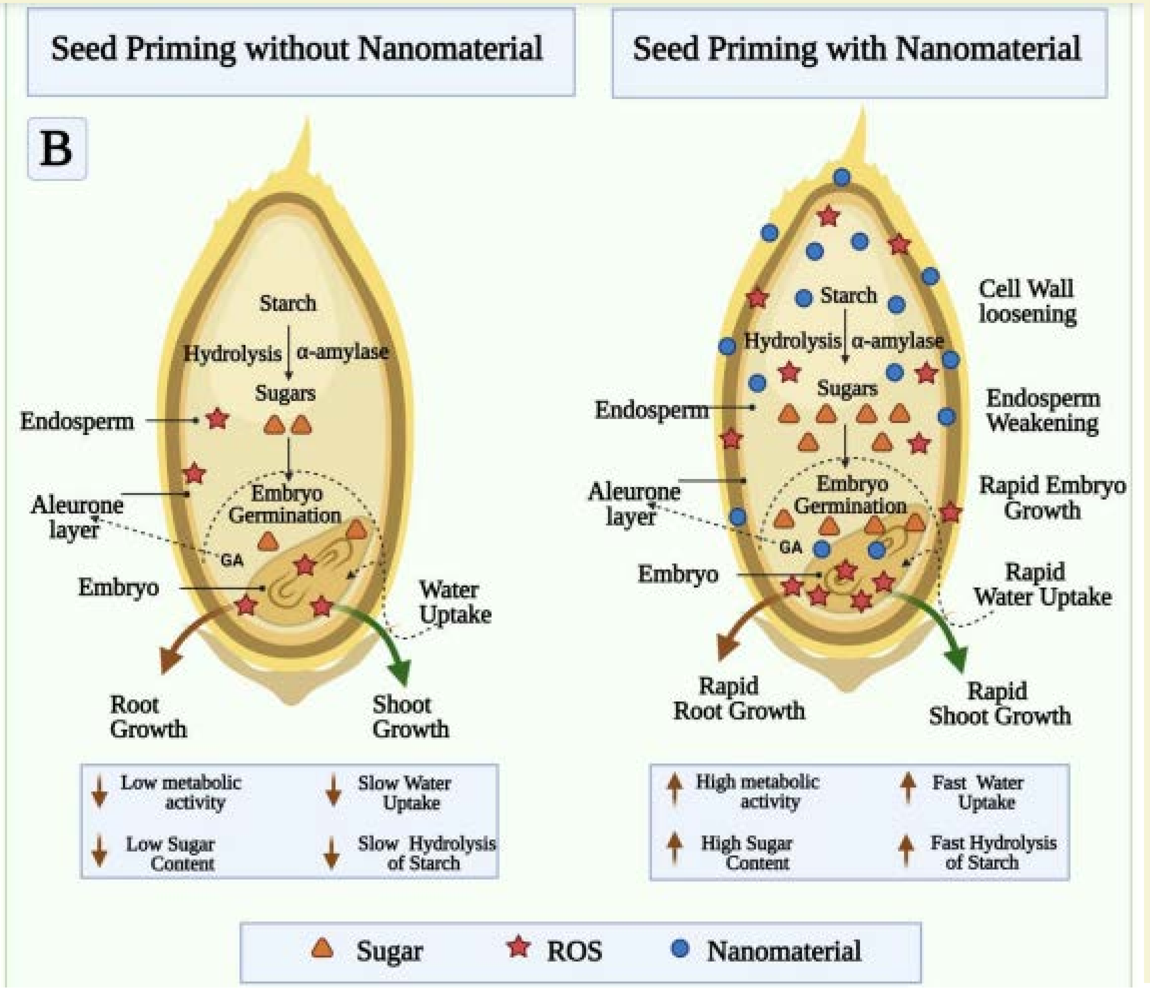
Effects of seed nano-priming on seeds and plants under abiotic and biotic stresses.
(a) Effects of seed nanopriming during the germination,
(b) effects of seed nano-priming on ROS levels, and
(c) potential effects under biotic and abiotic stresses.

do Espirito Santo Pereira, Anderson, et al. "Nanotechnology potential in seed priming for sustainable agriculture." *Nanomaterials, (2021) MDPI*

Molecular Targets of Seed Nanopriming



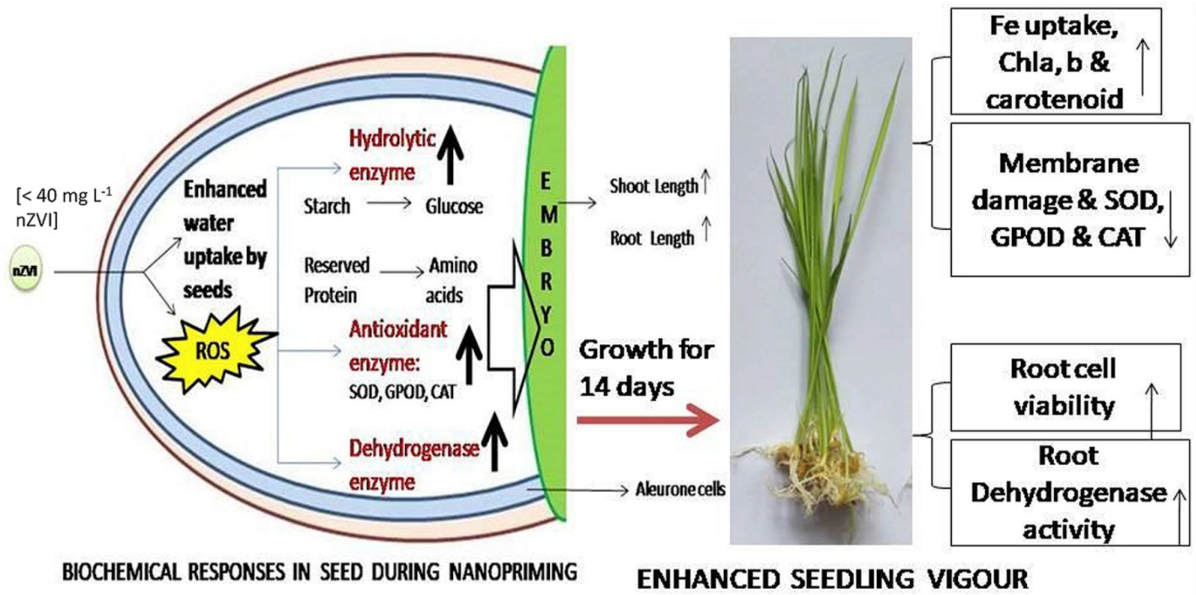
Physicochemical properties of nanomaterials influencing seed priming and its proposed mechanism. (A) The nanomaterial's size, shape, and surface chemistry make them a versatile candidate to modulate the seed priming phenomena via size-mediated diffusions and relocating to specific regions of the seed to activate synergistic mechanisms resulting in germination.



(B) The versatile catalytic function of NMs selectively play role in promoting enzymatic and biochemical pathways to promote root/shoot growth.

Shelar, Amruta, et al. "Sustainable Agriculture through Multidisciplinary Seed Nanopriming: Prospects of Opportunities and Challenges." *Cells (2021), MDPI*

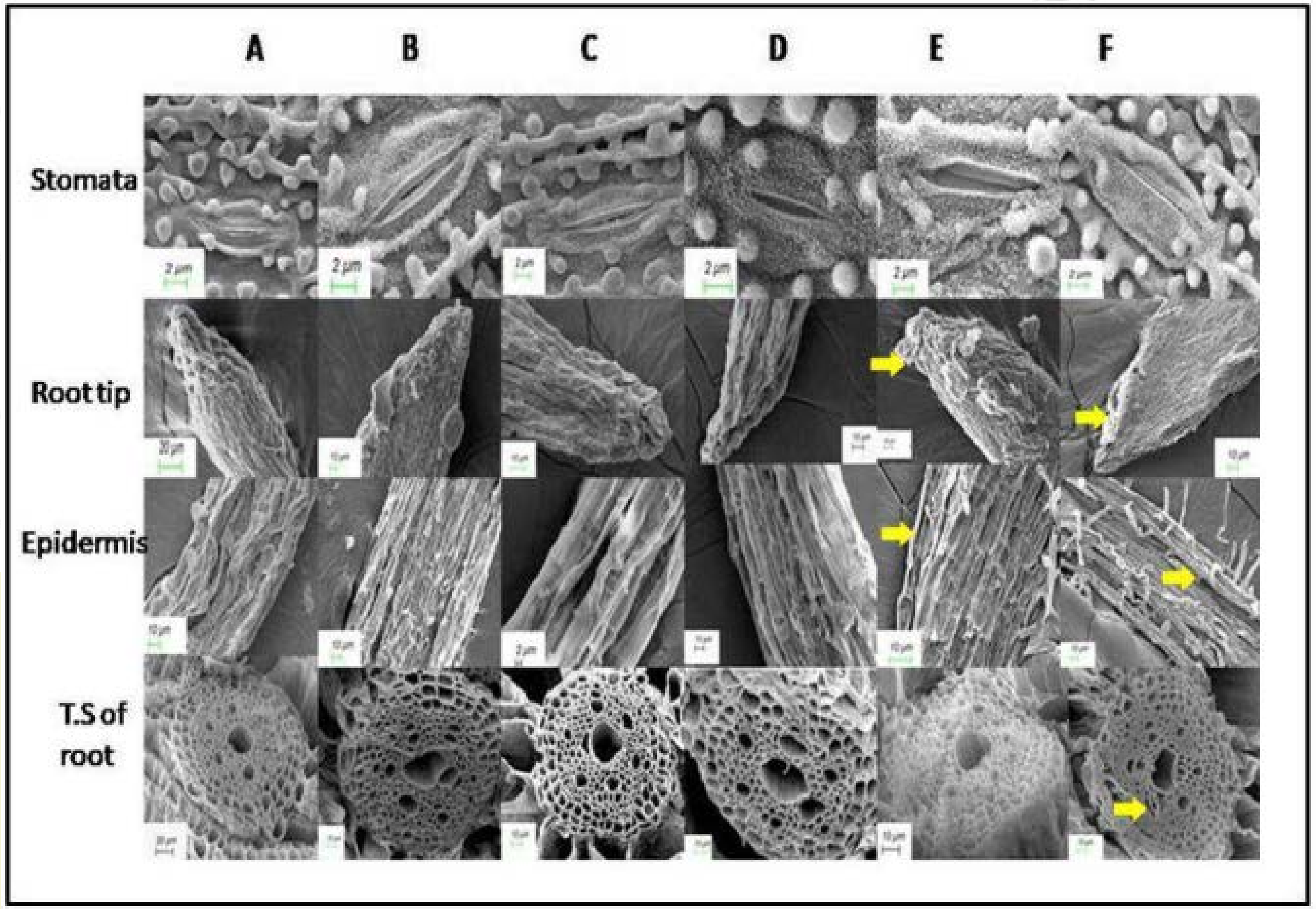
Seed Nanopriming with Zero Valent Iron Nanoparticles



Nanopriming with zero valent iron (nZVI) enhances germination and growth in aromatic rice cultivar (*Oryza sativa* cv. *Gobindabhog L.*

AAS study confirmed uptake of nZVI by the rice plants as maximum level of iron was found in the plants treated with highest concentration (i.e. 160 mg L^{-1} nZVI).

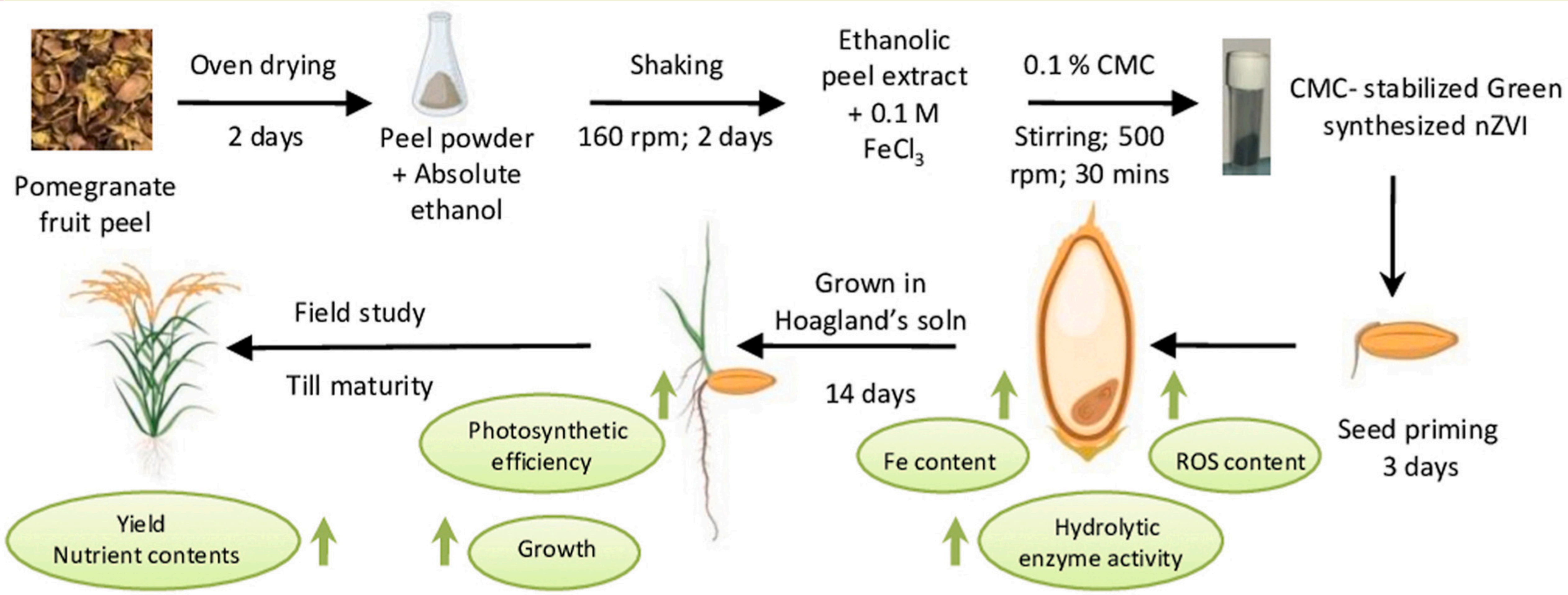
nZVI at low concentrations can be considered as priming agent of rice seeds for increasing plant vigour.



Scanning electron micrograph of 14 days old rice seedlings A,B,C,D,E and F represents control, 10, 20, 40, 80 and 160 mg L-1 nZVI primed seedlings. Arrows indicate damaged cells

Guha, Titir, et al. "Nanopriming with zero valent iron (nZVI) enhances germination and growth in aromatic rice cultivar (Oryza sativa cv. Gobindabhog L.)." *Plant Physiology and Biochemistry* 127 (2018): 403-413.

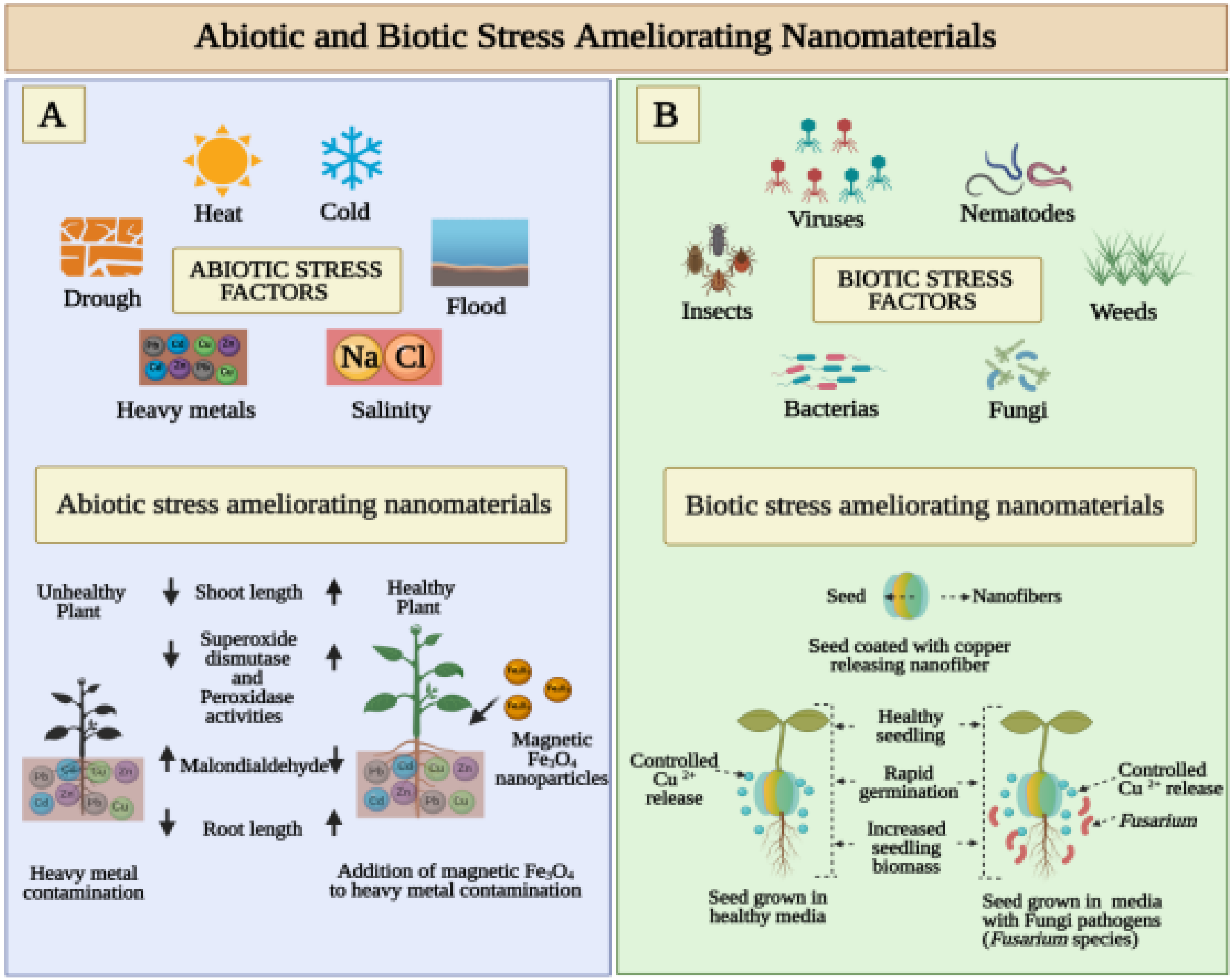
Seed Nanopriming with Zero Valent Iron Nanoparticles



Nanopriming with zero-valent iron synthesized using pomegranate peel waste: A "green" approach for yield enhancement in *Oryza sativa* L. cv. Gonindobhog

Guha, Titir, et al. "Nanopriming with zero-valent iron synthesized using pomegranate peel waste: A "green" approach for yield enhancement in Oryza sativa L. cv. Gonindobhog." *Plant Physiology and Biochemistry* 163 (2021): 261-275.

Effect of Nanopriming under Abiotic-Biotic Conditions



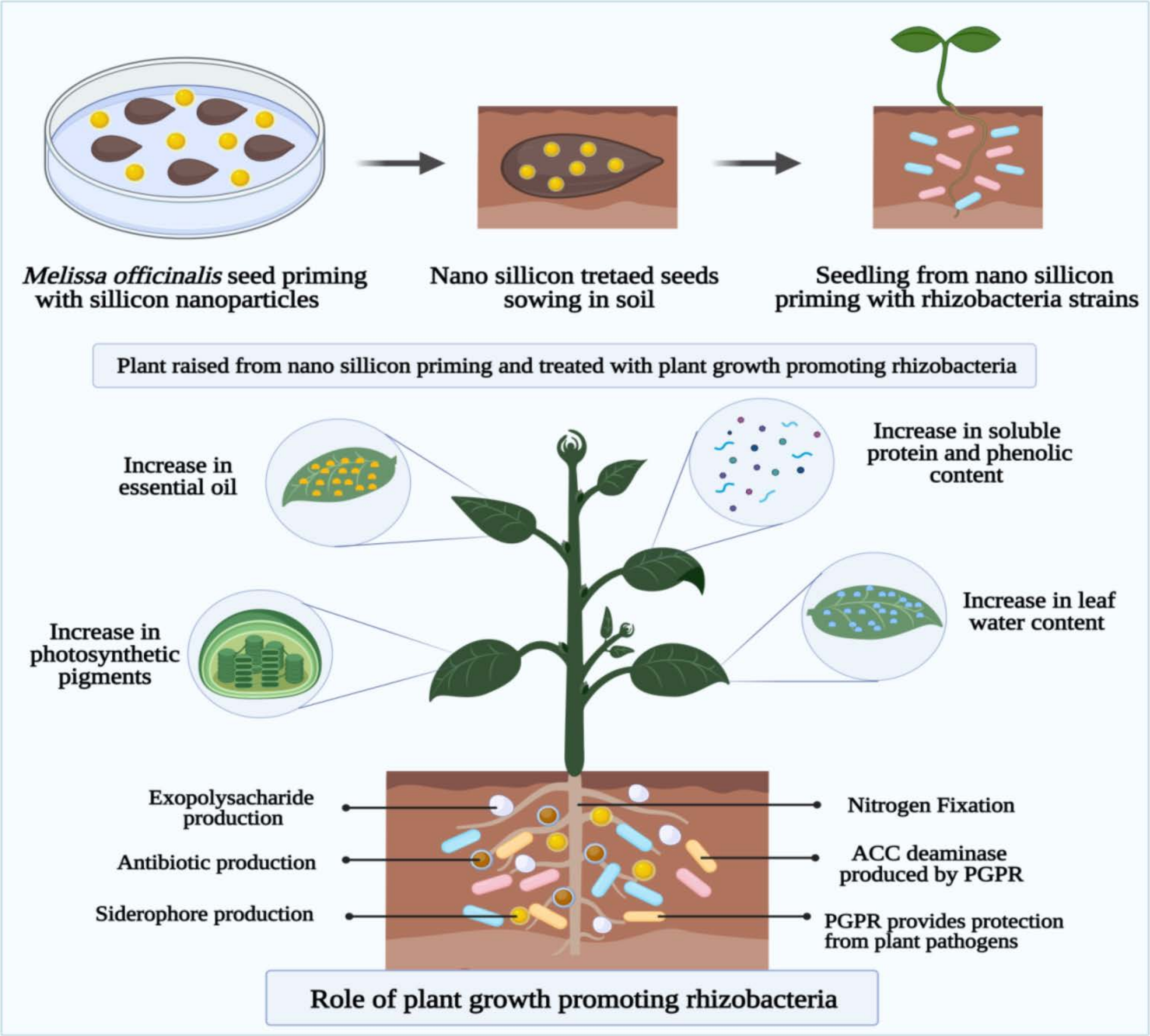
Effect of nanopriming agents to improve seed germination in abiotic and biotic stress conditions.

(A) Environmental conditions in combination with soil quality may pose stress to different phases of seed germination affecting biochemical pathways involved in the root-shoot development. The metal chelators and biocatalytic NPs could play a rescue role mitigating those abiotic conditions, giving a healthy plant development.

(B) Seed nanopriming with broad spectrum NMs with known microbicidal and anti-parasitic effect improve seed germination in biotic stress conditions boosting overall crop yield.

Shelar, Amruta, et al. "Sustainable Agriculture through Multidisciplinary Seed Nanopriming: Prospects of Opportunities and Challenges." *Cells. (2021) MDPI*

Effect of Combined Seed Priming Treatment of Nanomaterials with Microbes



The plant growth-promoting rhizobacteria (PGPR) combined seed nanopriming treatment with a selection of microbicidal nanomaterials without influencing the PGPR spares beneficial microbes of the soil and plant tissues.

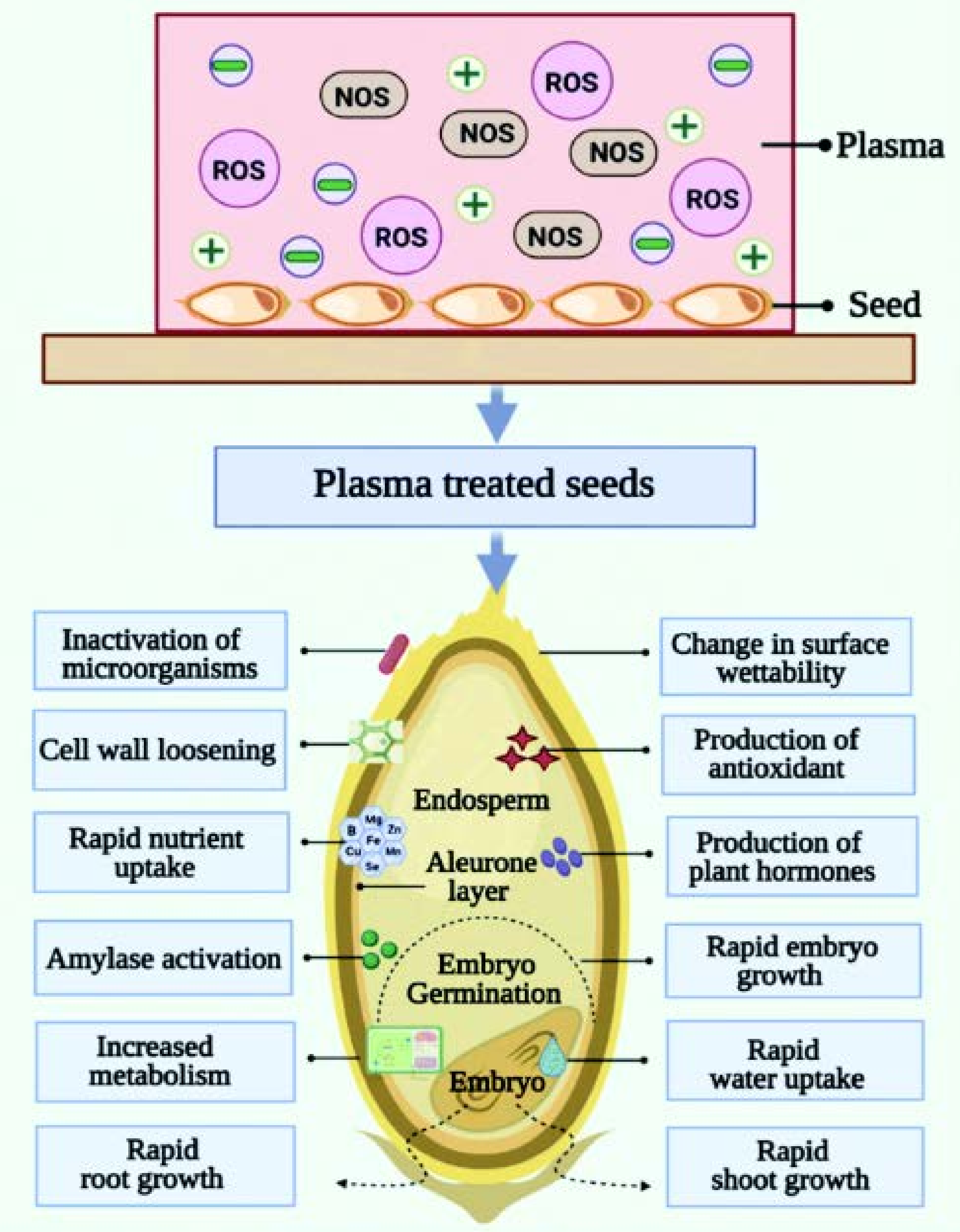
This promotes N_2-fixation improves harvest quality and yield via selectively increasing threshold towards biotic stresses.

Several studies on the interaction between nanomaterials and plant-benefitting bacteria, called Plant Growth-Promoting Rhizobacteria (PGPR), have been identified as a novel approach in sustainable agriculture.

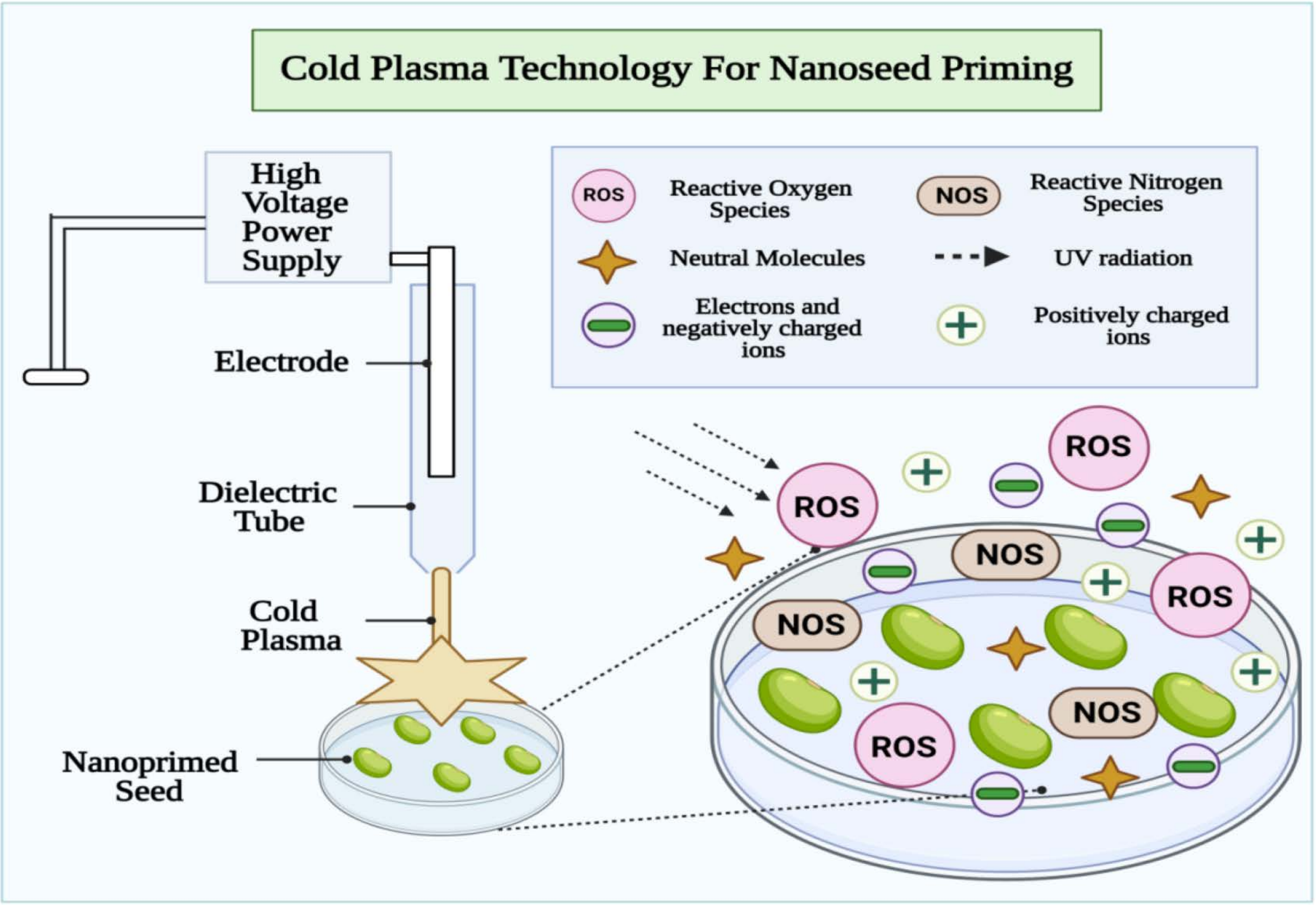
Combining seed treatment with colloidal solution of nanoparticles and microbial preparation results in a four-fold increase in nodule formation compared to control plants.

Shelar, Amruta, et al. "Sustainable Agriculture through Multidisciplinary Seed Nanopriming: Prospects of Opportunities and Challenges." *Cells.(2021) MDPI*

Effect of Combined Seed Priming Treatment of Nanoparticles and Cold Plasma Technology

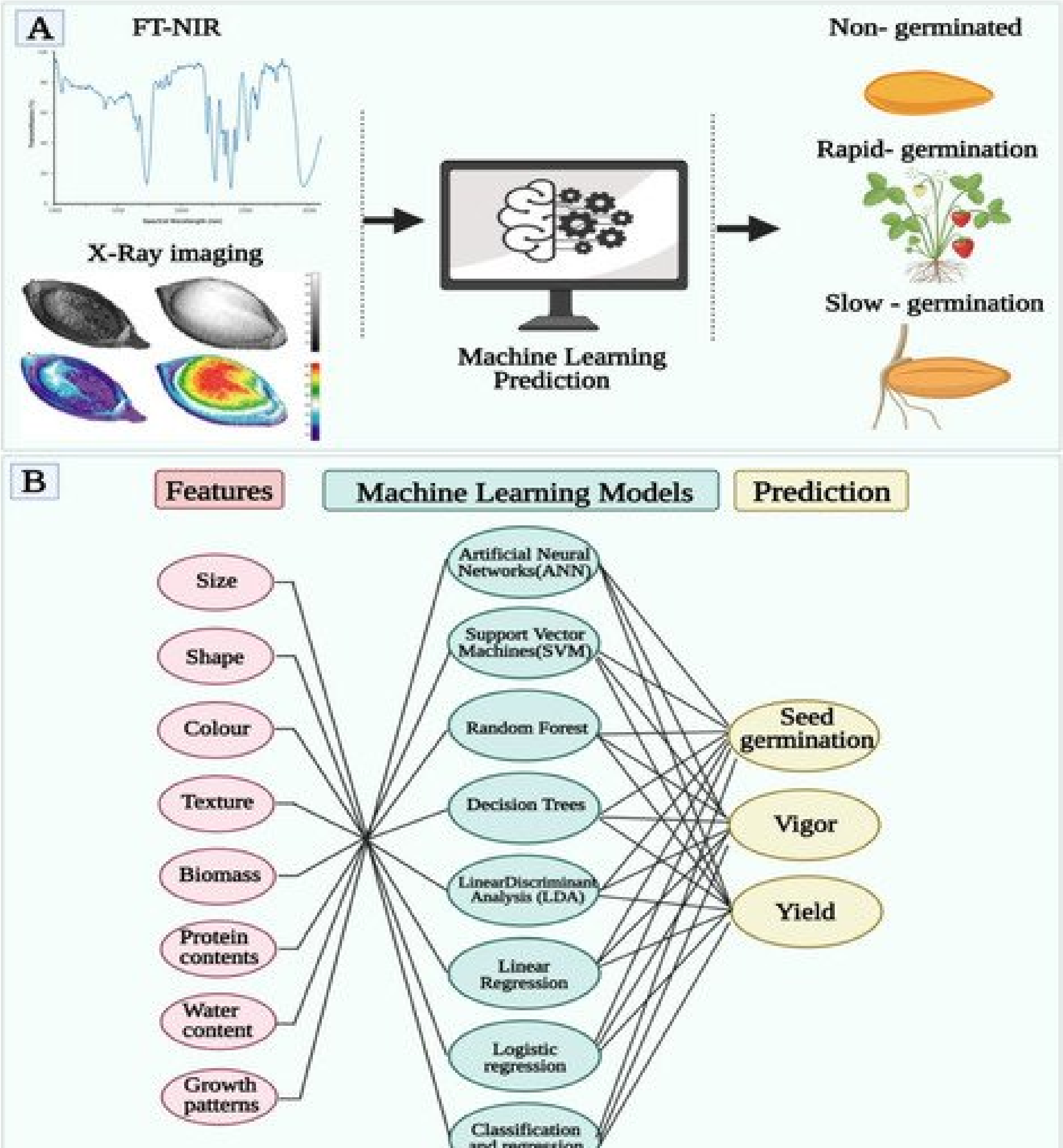


Reactive oxygen species (ROS) and reactive nitrogen species (NOS) generation by cold plasma at atmospheric or low pressure consequently affects seed germinating parameters, physiology, biochemical and molecular processes that are



The cold plasma (dielectric barrier discharge) mediated seed priming improve seed vigor via synergistical activation of plant defense machinery against ROS, supporting redox homeostasis in plant. Bases on cold vs. non-thermal plasma used in seed priming, the energetic electrons, charged particle, and reactive species are produced, which dissolve tough seed coat promoting water uptake and drought yield in the crop.

Artificial Intelligence and Machine Learning Technology for Nanoprimed Seed Diagnostics



(A) Artificial intelligence and machine learning may assist with infrared spectroscopy and X-ray image data mining and curation.

AI and ML may further complement via optimizing seed priming technology based on chemi analytic profiling for heat and moisture content assisting in breaking seed dormancy.

(B) Post nanopriming, AI and ML tools can be used to predict seed germination, vigor, and yield of nanoprimed seeds.

As shown in **Figure**, by using these softwares, post seed nanopriming diagnosis can be done to predict nanoprimed seeds viability and phenotypic analysis.

As of today, germination scoring is typically done by human observation, and therefore, has a limited frequency, scale, and accuracy.

In order to handle this bottleneck, many attempts have been made to automate both seed diagnostics and associated phenotypic analysis, with more than one research-based solution such as germinator, phenoSeeder, and the MultiSense tool as a result .

Limitations and Future Prospects of Nanopriming Techniques

- No clear trend regarding priming responses depending on the taxonomic position of the species.
- Nanoprimed seed material can be less stable, and higher maintenance costs for seed companies and farmers are consequently incurred.
- Possibly requiring an additional treatment may be both an extra cost and a source of variability because germination potential may not be fully restored.

- The treatment parameters need to optimize, in order to achieve a reproducible beneficial effect of priming on seeds.
- Important to find out at which parameters nanopriming is showing toxicity to seeds and how they will affect future plant generations.
- There is no clear knowledge of the mechanisms of changes occurring in seeds during and after nano priming treatment.

Acknowledgments: BfR colleagues, FG75 and Collaborators

Rajendra Patil (Ph.D, Nanobiotechnology)
Assistant Professor,
Department of Biotechnology,
Savitribai Phule Pune University, India.

Amruta Shelar (Msc, M.Tech)
Ph.D scholar,
Chemical Engineering & Biotechnology
Department of Technology,
Savitribai Phule Pune University, India.

Maria Fernanda Santill
The Nanoinformatics Innovation Centre,
La Plata, Buenos Aires C1062, Argentina