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SEED PRIMING: AN OLD EMPIRICAL TECHNIQUE WITH NEW HOLISTIC APPROACHES TO INCREASE THE TOLERANCE OF PLANTS TO SALT AND DROUGHT STRESS

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ABSTRACT

In the current climate challenging scenario, such as increasing salt and drought stress, the prerequisite to enhance crop performance has become more crucial. As the growth and development of crops are adversely affected due to several biotic and abiotic stresses. Seed priming, a time-honoured agricultural practice, has emerged as a promising tool for enhancing plant stress tolerance. Seed priming represents an alternative, economical and applicable method that can intensify tolerance to drought stress by promoting quicker and improved seed germination. Seeds that undergo priming are capable of retaining a memory of earlier stress exposures, helping them to defend against oxidative damage through the earlier initiation of cellular defense systems, reduce water uptake time, increased levels of germination-stimulating compounds and better osmotic balance. However, a deeper understanding into the metabolic processes occurring during priming is essential to optimize the utilization of this approach. This review focuses on the morphological, physiological, biochemical, and molecular adaptations induced by seed priming to strengthen drought resistance in crop species. This review emphasizes the evolving scenario of seed priming techniques, shedding light on the historical context of this method while delving into modern, holistic approaches. Furthermore, this review explores the mechanisms by which seed priming confers salt and drought stress tolerance. Primed seeds exhibit improved water uptake, enhanced antioxidant activity and the activation of stress-responsive pathways. These mechanisms collectively contribute to higher germination rates, faster seedling emergence, and increased overall plant vigour under adverse conditions.
***Keywords*:** Abiotic stresses, Antioxidant activity, Crop performance, Seed priming, Stress tolerance.

Introduction

The ability to feed an ever-expanding worldwide population in the aspect of mounting environmental challenges is one of the most essential issues of our time. Tropical agricultural centres are particularly exposed to climate change extremes such as heavy rainfall, droughts and floods (Sarkar *et al.*, 2020a; González-Orozco *et al.*, 2020). Among these challenges, salt and drought stress have emerged as formidable adversaries to crop production, threatening food security worldwide. As climate change increases, the frequency and severity of these stressors will increase, necessitating innovative strategies to bolster the resilience of agricultural systems. Seed priming, an age-old agricultural practice rooted in empiricism, has undergone a remarkable transformation in recent years, evolving into a cutting-edge approach that holds great promise in addressing the complex issue of plant stress tolerance under adverse conditions (Parera and Cantliffe, 1994).

Historically, seed priming has been employed by farmers across diverse cultures for generations. This ancient technique involves subjecting seeds to controlled hydration and dehydration processes, often utilizing water as the primary medium. The fundamental principle behind seed priming is to initiate the germination process, without allowing the seeds to fully sprout, by imbibing them with a specific quantity of water for a predetermined period. The soaked seeds are subsequently dried to their initial moisture content, and the dormant seeds gets primed and show faster germination, increased vigour, improved crop performance and enhances yield potential when sown in the field even under adverse conditions (Marthandan *et al.,* 2020; Ibrahim, 2016). In recent decades, seed priming has undergone a profound evolution from a traditional and empirical practice into a scientifically refined and technology-driven method. Researchers have harnessed the power of seed biology, genomics, and molecular biology to develop comprehensive approaches that go far beyond simple hydration-dehydration cycles. These modern seed priming techniques are designed to address the specific challenges posed by salt and drought stress, and they do so with an unprecedented level of precision and effectiveness. By tailoring the priming process to induce specific biochemical and genetic responses, scientists are now able to equip seeds with a heightened capacity to endure the harsh conditions associated with salt and drought stress. These advanced techniques encompass a spectrum of interventions, including osmo-priming, hormonal priming, and the incorporation of beneficial microorganisms, all finely tuned to optimize stress tolerance and crop performance.

In this exploration of seed priming, we delve into the historical roots of this practice and trace its evolution into a vital component of contemporary agricultural science. We also examine the latest scientific insights and innovative strategies that promise to revolutionize our ability to improve the tolerance of plants to salt and drought. As the global agricultural community seeks sustainable solutions to meet the challenges of the 21st century, seed priming emerges as a beacon of hope, offering a bridge between ancient wisdom and modern science in the quest for food security in an increasingly uncertain world.

Brief History of Priming

Since the early days of agriculture, it has been clear to humans that many seeds do not easily or uniformly germinate. Greek farmers recognized this technique and adopted it for sowing of seed known as seed priming. Theophrastus (372-287 BC) studied the seed physiology and proposed that the process of germination could be temporarily interrupted. He suggested that soaking of the cucumber seeds in milk or water before planting could promote earlier and more vigorous germination. Further research indicated that Roman farmers also practiced pre-hydration of legume seeds to enhance germination rates and synchronization. In 1664, Evelyn noted that the temperature before sowing can affect subsequent germination of the seed. In 1779, Ingenhousz has studied the effects of light on seedling and the morphological process involved in the germination of seeds. Then, in 1920, the discovery of the role of plant hormones in reservoir mobilization, tolerance to seed drying, cell division, and cell elongation occurred (Lutts *et al.,* 2016). The term "seed priming" was coined by Heydecker in 1973. Since then, seed priming has been effectively applied to improve emergence of the seed and germination of the seed, particularly under stressful conditions (Sivasubramaniam *et al.,* 2011).

Soil Salinity and their effect on growth and development of plants

Salinity poses considerable challenges to global food production, climate change mitigation, and the growth of the global population. Mostly in arid and semi-arid areas, it severely restricts agricultural sustainability and productivity (Zörb *et al.,* 2019). The issue of salinity is a worldwide concern, impacting around 7% land area of the Earth, including 20% of agricultural lands and 33% of irrigated areas. It is estimated that this results in a global yield loss of around 20% (Parihar *et al.,* 2014; Jamil *et al.,* 2011).

Furthermore, the annual loss of agricultural land due to salinization is estimated to be 10 million hectares (Pimentel *et al.,* 2004). Climate change, contaminated artificial irrigation, and poor land management are some of the factors that are expected to make this issue worse in the future. By 2050, it is expected that more than half of the world's arable land will be covered by salinity-affected areas if effective and long-lasting control measures are not implemented (Jamil *et al.,* 2011). Salinity is a significant stressor that negatively impacts seed germination in crops. It delays the germination process and lowers germination rates in addition to inhibiting it. Currently, about 30 crop species account for 90% of human food and unfortunately, most of these crops are not salt-tolerant; they are, in fact, salt-sensitive, known as glycophytes (Zörb *et al.,* 2019). Moderate salinity conditions, typically characterized by an electrical conductivity (EC) of 4-8 dS m^{-1} or approximately 40-80 mM NaCl, have been associated with considerable losses of yield in these crops (Koyro *et al.,* 2008).

Drought stress and its impact on agriculture

Drought and extreme temperatures have a negative consequence on both the development and quality of plants (Kosar *et al.,* 2020, Raja *et al.,* 2020). These environmental factors can lead to a sudden decrease in water availability, resulting in drought stress, particularly in rain-fed ecosystems, which are crucial for global agriculture (FAO, 2020). Agriculture is one sector that is particularly susceptible to water scarcity. In fact, it has been known to cause significant decreases in crop productivity, with yield potential dropping anywhere from 40% to 60%, particularly in regions that rely heavily on rainfall (FAO, 2020).

Drought can have a detrimental impact on different stages of crop development. These phases consist of maturity, vegetative and reproductive growth, and seed germination. The degree to which each stage is impacted depends on the intensity and length of the drought stress. The germination of seeds and the successful establishment of seedlings are particularly crucial for crop production and yield (Anjum *et al.,* 2017). This is especially true when faced with salinity stress. One method that has shown assure in the field of modern-day crop management is seed priming. It offers a way to effectively manage both biotic and abiotic stressors, promoting environmentally friendly and sustainable agricultural practices (Fig. 1). This well-established method, known for its ability to enhance germination of the seed and stress responses (Lal *et al.,* 2018), offers a direct and non-intensive approach that has demonstrated significant improvements in plant establishment and growth, particularly in challenging environmental conditions on farmer's fields.

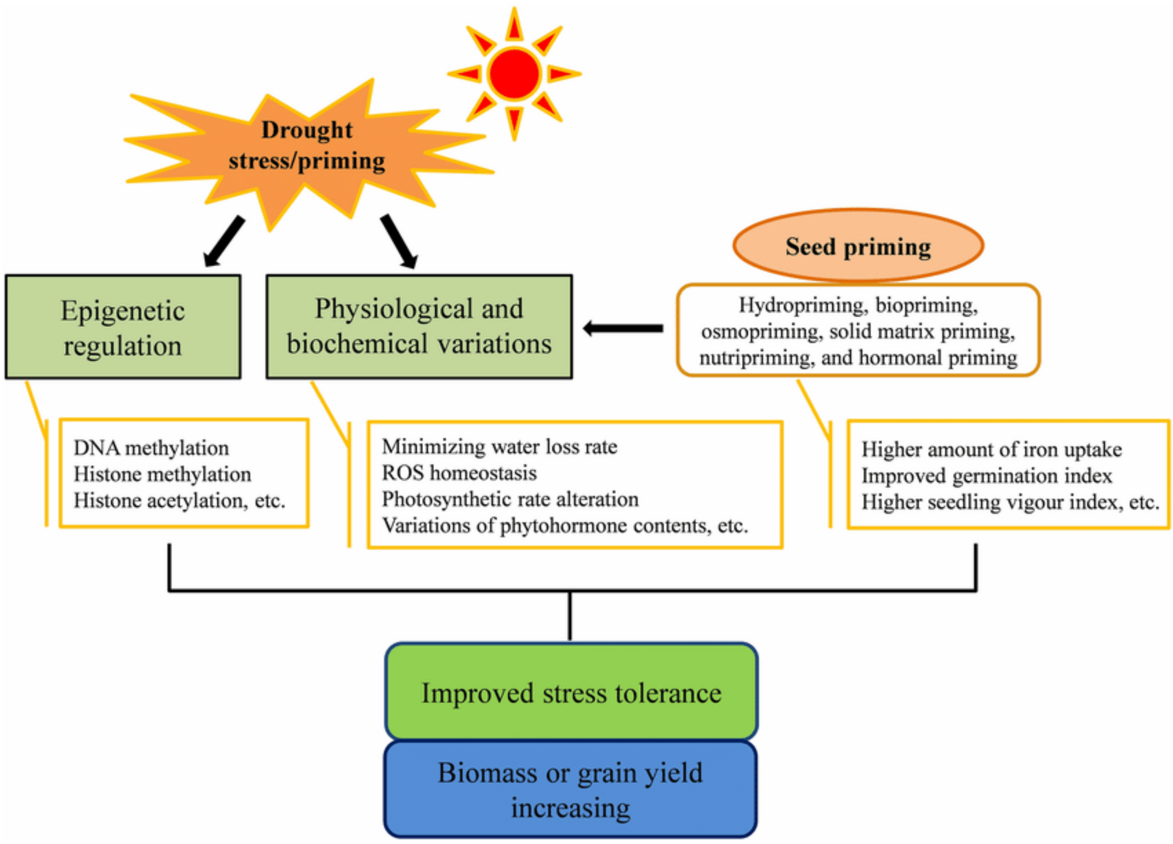

Fig. 1 : An overview of how plants respond to drought stress and how seed priming affects drought tolerance.

Seed Priming

In agriculture, farmers often face challenges related to poor seedling emergence and weak seedling vigour, which significantly influence the final crop yield. To improve production potential in adverse environmental conditions viz., soil salinity and drought stress, various seed technologies have been recommended. These methods include seed priming, seed coating, humidification, and wetting of seeds, all of which are effective techniques aimed at enhancing the development and performance of seedlings in the field, particularly how they respond to environmental stressors (Farooq *et al.,* 2019). One such precise technology frequently active in numerous Asian countries is seed priming. This technique ensures synchronized seed growth even under adverse conditions of the soil and water (Kumar *et al.,* 2018; Singhal *et al.,* 2019; Kumar *et al.,* 2020). It is considered a practical and farmer-friendly approach that promotes uniform seed emergence and robust seedling vigour, ultimately resulting in higher yields for various agricultural crops, especially in challenging conditions of the environment (Jisha *et al.,* 2013; Paparella *et al.,* 2015).

Changes Occur While Priming

Seeds are hydrated for a specific duration during the priming process without radicle protrusion (phase I) (Chen & Arora, 2011) initiating the necessary metabolic events for early germination to activate the pre-germinative phase II (metabolic activation) in which different biochemical processes are triggered (Zhang *et al.,* 2015) and subsequently, they are dehydrated to regain their primary dry weight (Bose *et al.,* 2018) and in phase three, it will ultimately begin the germination process in the phase three (germination) during which the radicle protrudes from the seeds (Fig. 2) (Rouhi *et al.,* 2011, Paparella *et al.,* 2015). The priming of seeds proved to be useful in achieving uniformity in germination, activating various biochemical processes like enzyme activation, repairing cells, protein synthesis, and augmenting antioxidant defense mechanisms when compared to seeds that were not primed (Jafar *et al.,* 2012).

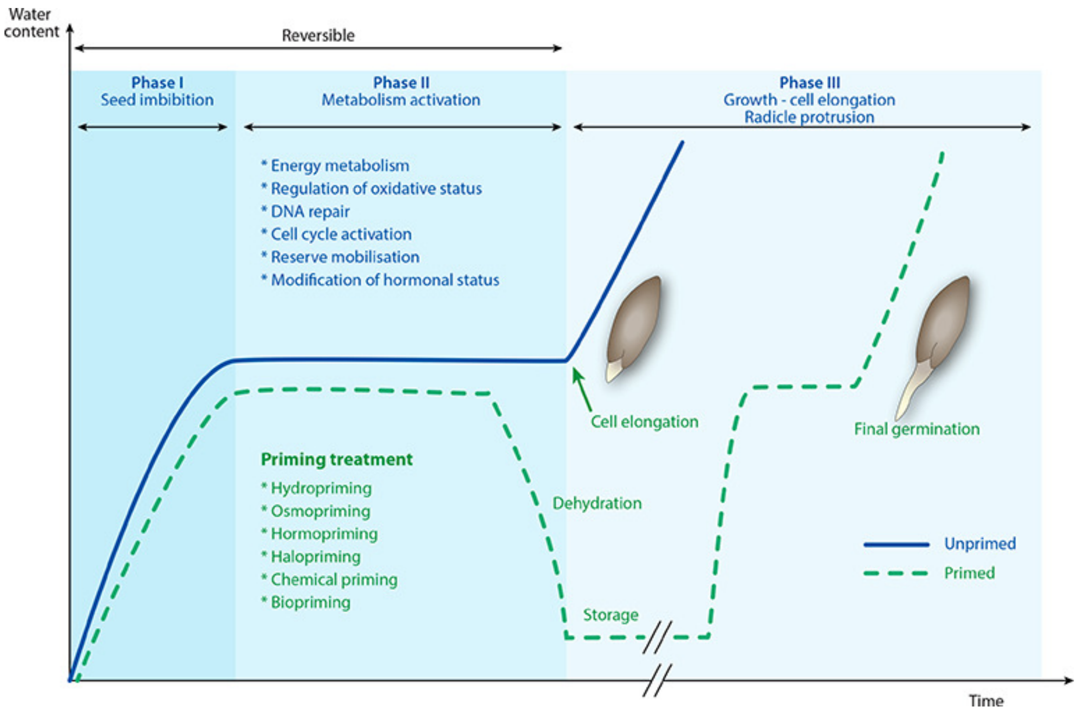

Fig. 2 : Phases of germination and seed hydration curves for primed and unprimed seeds (Jafar *et al.,* 2012).

"Various organic and inorganic chemicals have been used to enhance crop growth by seed priming. Based on the specific chemicals used, their characteristics, and their effects, seed priming technique is classified into an array of methods including hydro-priming, osmo-priming, chemical priming, biopriming, hormonal priming, solid-matrix priming, nutri-priming or even nano-priming (Jisha *et al.,* 2013; Bose *et al.,* 2018).

The various seed priming techniques listed below, along with the mechanisms that improve crop plants capacity for tolerance

Hydropriming

Hydropriming is an environmental friendly and cost-efficient method of enriching seeds by soaking them in plain water and then drying them to their primary moisture content before planting (Singh *et al.,* 2015). It assists in the seed hydration, but also turns out to be better since there is a constant flow of oxygen. It also promotes the action of hydrolytic enzymes such as xylase, cellulase and amylase, which in turn catalyze stored food reserves such as carbohydrates, proteins, and lipids to simpler compounds like adenosine triphosphate (ATP) for the early metabolic activities (Zulueta-Rodríguez *et al.,* 2015). There have been certain studies that have shown the hydric branding as leading to a betteraged seed vigour such as uniformity in germination, earlier emergence of seedlings and better growth and development of crops such as rice, chickpea (Kaur *et al.,* 2002) and faba bean (Damalas *et al.,* 2019) in drought stress conditions when compared with seeds that have not been treated using hydropriming (Singh *et al.,* 2015). Moreover, hydropriming has been shown to significantly improves germination rate for plants under sub-optimal conditions of temperature and drought stress (Cheng *et al.,* 2017).

Osmopriming

Osmopriming is a common way to get seeds ready. It soaks seeds in a solution with low osmotic pressure and air for different lengths of time changing how much water they can take in (Lutts *et al.,* 2016). These solutions let water enter the seeds, which starts the processes before sprouting without making the root come out. People often use PEG (polyethylene glycol), KCl, $CaCl_2$, $MgSO_4$, NaCl, mannitol, KH_2PO_4, and KNO_3 for osmopriming, with PEG being the top pick (Singh *et al.,* 2014). Polyethylene glycol’s are a large molecule that doesn't get into the seeds much, which prevents it from damaging the cells and reduces the amount of water that the solution draws. When seeds soak up water in a controlled way during osmopriming, it cuts down on harmful oxygen molecules (ROS) (Katarzyna *et al.,* 2019). Not having enough water causes stress, but less stress means fewer ROS. Using PEG to prime seeds has shown to make caraway seeds sprout better and grow heavier shoots, both when fresh and dry (Mirmazloum *et al.,* 2020).

Chemical Priming

Various chemical agents like chitosan, chollne, putrescine, selenium, KH_2PO_4, $CuSO_4$, $ZnSO_4$, and Paclobutrazol play a role in the use of chemo-priming techniques which help increase the yield and stress handling capabilities of plants (Jisha *et al.,* 2013). These chemicals are key to making plants tougher against drought. They do this by protecting cells, getting rid of toxins, and keeping proteins and ions balanced. These agents are good at getting through seed coats, which helps plants take in nutrients and use water more. Take butenolide, for instance. Demir *et al.* (2012) explored that treating seeds with it before planting makes seedlings stronger and helps them sprout better in pepper and salvia plants. Hameed and Iqbal, (2014) found that priming seeds with mannose helps plants deal with drought better. It does this by increasing antioxidants cutting down on damage from oxidation, and building up more reducing sugars to control water balance in cells.

Upadhyaya *et al.* (2017) have used SiO_2, Ag, and ZnO as nanoparticles to prime seeds. This method helps seeds sprout better and grow stronger. Hussain *et al.* (2016) showed that priming with $CaCl_2$ helps seedlings growth, increases the number of shoots, makes plants taller, and leads to heavier and more numerous grains, when wheat faces drought. Singh *et al.* (2023) studied that the application of GA_3 significantly enhanced the germination and seedling development of Tulsi seeds when exposed to specific temperature conditions. Kaya *et al.* (2020) studied how priming maize hybrid seeds with KNO_3 and urea helps them deal with drought and salt stress. He also observed that this method makes roots longer, produces more proline, improves germination, boosts seedling growth, and increases protein content.

Biological Priming

In biopriming, bacterial inoculants with biological activity are incorporated into the priming solution for seed imbibition (Mahmood *et al.,* 2016). Fungicides, biocontrol agents, and Plant Growth Promoting Rhizobacteria (PGPRs) are added to the priming solution and all are aimed at improving germination and seedling vigour. This method helps align crop performance parameters, such as growth, yield and crop stand with their capacity to endure biotic and abiotic stress factors, as studied by Rakshit *et al.,* 2015. Among the well-known PGPRs used to enhance drought tolerance are *Trichoderma, Pseudomonas*, *Azotobacter, Azospirillum*, and *Agrobacterium* (Reddy, 2013). When *Trichoderma* is used in biopriming, it promotes the synthesis of growth hormones in plants, leading to improved drought tolerance (Harman, 2006). In addition, the application of *Trichoderma* in biopriming positively increases the activity of L-phenylalanine ammonia-lyase, which affects the redox state of plants and fostering greater root vigour under drought conditions. This not only contributes to improved drought tolerance but also fortifies the plants through physiological defense mechanisms against oxidative damage. Moreover, it enhances resistance to diseases by creating a protective coat on the seeds (Shukla *et al.,* 2014).

Hormonal Priming

Soaking seeds in a solution containing several hormones that promote plant growth, including ascorbate, kinetin, salicylic acid (SA), abscisic acid, and GA_3, is known as hormonal priming. This method has been shown to enhance crop resistance to drought and rising temperatures (Wei *et al.,* 2017; Bakhtavar *et al.,* 2015). Furthermore, rice seeds that are primed with spermidine and polyamines show enhanced drought tolerance (Zheng *et al.,* 2016). A similar growth-regulating effect is observed when seeds are primed with abscisic acid (ABA) under conditions of restricted soil moisture. This is achieved through the aggregation of osmoprotectants in the system of plants (Umezawa *et al.,* 2010). When the gibberellic acid applied during priming of the seeds it enhances the germination of rye seeds and increases the synthesis of antioxidants, particularly during stress conditions (Ansari *et al.,* 2013). Priming with benzyladenine (BA) before planting significantly increases root biomass, enhances soybean growth, and conversion efficiency, indicating its function in fostering drought tolerance in soybeans.

Enhancing germination and reducing the germination time can be achieved by optimizing the concentrations of priming reagents such as sodium chloride (NaCl), thiourea, ascorbic acid, salicylic acid, hydrogen peroxide (H_2O_2), gibberellic acid, and ascorbic acid. Sunflower seedling growth is as well influenced by these changes (Kohli *et al.,* 2018). In the case of cotton and rapeseed cultivation numerous priming agents, including jasmonic acid (JA), SA, ABA, GA, ethylene, potassium nitrate (KNO_3), monopotassium phosphate (KH_2PO_4), polyethylene glycol (PEG-6000), mannitol, and NaCl, have been found to enhance resistance to abiotic stresses such as lead (Pb), drought, and temperature changes (Kohli *et al.,* 2019).

Solid Matrix Priming

The priming solution's matrix potential is changed during solid matrix priming (SMP) to influence how seeds absorb water by using solid matrix materials that produce matrix forces. These forces help hold water and slow down the uptake of solutes by seeds (Damalas *et al.,* 2019). This gradual solute absorption keeps seeds sufficiently moist for longer periods, improving their resilience to drought conditions. It's important to mention that materials with solid matrix generally have a lower bulk density and osmotic potential but can hold a significant amount of water. Matrix priming offers the benefit of providing a substantial amount of oxygen to seeds during the priming phase. It has been shown that SMP (solid matrix priming) enhanced the carrot emergence and establishment (Lutts *et al.,* 2016) and also enhanced the germination and vigour of soybeans. There was also a significant increase in drought tolerance in peas when primed with chitosan at 5% moisture in the soil (Guan *et al.,* in 2009). Solid matrix conditioning appears to be a promising method for improving seed germination across several crop species, especially in horticultural crops. Although this technique has produced significant outcomes for number of crops, more extensive research and exploration are necessary to fully unlock its potential.

Nutripriming

Under osmotic stress conditions, for germination and growth, the plants require more water and nutrients. Nutripriming is a new technique to improve the amount of water available and essential nutrients during seed germination by adding magnesium, zinc, and boron. Magnesium activates metabolic enzymatic reactions whereas boron takes part in sugar transportation in leaves (Ullah *et al.,* 2019; Iqbal *et al.,* 2016). Therefore, their application at priming increases overall physiological activities of crops (invasive-tolerant) under water-stressed environments (Alam *et al.,* 2015c). Zinc remarkably improves the grain development activity at early phases of seeds/plants. Rehman *et al.* (2013) revealed significant enhancement in the productivity as a result of priming chickpea seeds with boron which might have enhanced effective fertilization and seed set (Shivay *et al.,* 2014). Similarly, zinc primed chickpea enhance canopy during crop growth period, increased drought tolerance through accumulating proline contents into plant cells, improved yield attributes.

Including calcium acts as a secondary messenger that causes an increase in the accumulation of osmolytes and antioxidants under stress, adding it to seeds during priming has become a successful and practical way to increase stress tolerance in a variety of crops (Tabassum *et al.,* 2018; Jafar *et al.,* 2012). Moreover, nutripriming helps the crop plant produce antioxidants and develop tolerance against the environmental stress (Farooq *et al.,* 2017).

Nano Priming

Nanotechnology, a rapidly expanding field, offers numerous industrial applications across diverse sectors, including electronics, textiles, pharmaceuticals, energy, food, cosmetics, and environmental bio-remediation (Moll *et al.,* 2016). Recently, nanotechnology has piqued the interest of the agriculture sector, with remarkable advancements in seed biology applications (Banik & Pérez-de-Luque, 2017). Extensive research has been conducted by various scientists to explore the use of nanoparticles (NPs) to protect crops from biotic and abiotic stresses, while also enhancing crop yields (Li *et al.,* 2016). Numerous studies about the interaction between nanoparticles and plants have been published, and a wealth of useful data has been gathered on a variety of research platforms and also accumulated a lot of valuable data on various research platforms. But, it is essential to note that NP impacts for different plant species was varied significantly with several physiological and molecular traits. Moreover, the reaction of NPs was changed by its characteristic properties including size, shape, synthesis action, and chemical composition (Rastogi *et al.,* 2017). Singh *et al.* (2024) reported that the nanoscale size of coatings contribute to healthier adhesion, regulated release and stronger interactions with the seed surface, which support normal germination and healthy seedling growth. Furthermore, these nano-coatings enhance seed physiological quality and encourage endurance against abiotic stresses like high salinity, drought and high temperatures. Nanoparticles influence the development of plants for entering the cell wall resulting in the alteration of some morphologic and physiologic aspects as shown in Fig. 3 (Guan *et al.,* 2009). For example, Si NPs have been shown to ameliorate drought induced growth repression and improve barley plant recovery from drought by altering morphophysiological characteristics (Ghorbanpour *et al.,* 2020). It had been shown that the applying of Si NPs enhanced cucumber yield and growth in both saline and water-stressed environments (Alsaeedi *et al.,* 2019). Seed germination has been another perspective for studying impacts of nano-priming using various NPs including zinc oxide, iron, silver NPs and titanium oxide (Panyuta *et al.,* 2016). Nano-priming has improved photosynthetic attributes, maintained biochemical equilibrium and augmented biomass in wheat seedlings. For instance, shoot length and root-shoot white desert biomass increased due to ZnONPs under salt stress exposed seedlings (El-Badri *et al.,* 2021). With these discussions it is coherently established that nano-seed priming entirely regulates ionic homeostasis, secondary metabolites, antioxidant enzyme contents, along with photosynthetic attributes and minimizes oxidative stress for the amelioration of salinity as well as drought impacts on plants (Fig. 4).

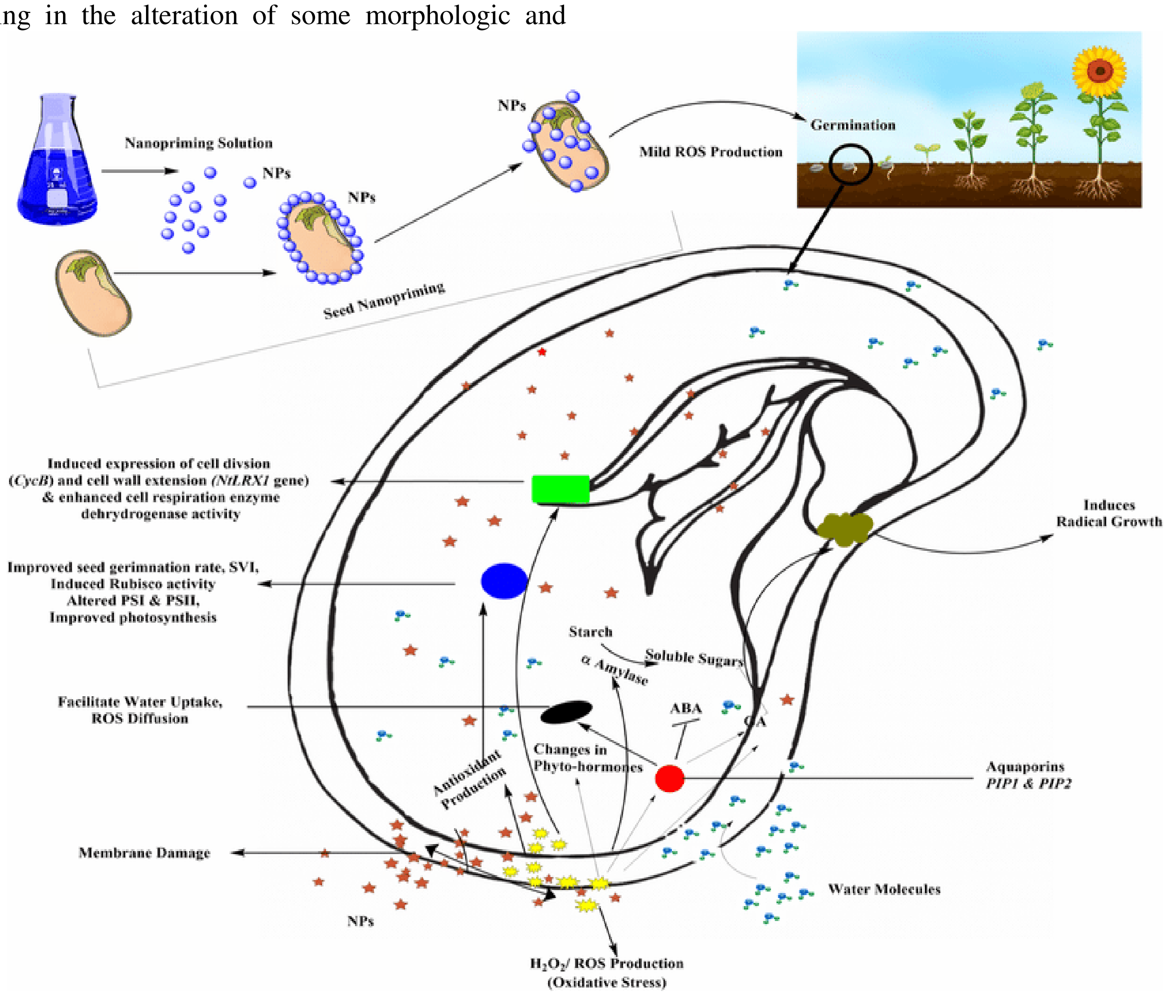

Fig. 3 : Enhancing Seed Germination and Growth Through Nano-priming Under Saline Conditions

Table 1 : Effects of Nano-priming agents on crops yield

Sr. No.	NPs agents used in studies	Effects on different crops	References
1.	Iron-oxide nanoparticles	Nano-priming led to improvements in sorghum seedling strength, metabolic activity, plant biomass, and moisture content in foliage	Maswada *et al.,* 2018
2.	Manganese (III) oxide nanoparticles	Boosted antioxidant enzyme levels and better adaptation to salinity stress in chilli plants (*Capsicum annuum* L.)	Ye *et al.*, 2020
3.	Copper and Iron nano particles	Enhanced enzyme functions, improved biochemical and antioxidant responses, greater tolerance to abiotic stress, and increased yield in wheat (*Triticum aestivum* L.)	Yasmeen *et al.,* 2017
4.	Nanoparticles of cobalt and molybdenum oxides	Enhancement of seed and seedling vigour, morphological traits, biomass production, and enzymatic activity in soybean (*Glycine max* L.) through nano-priming	Chau *et al.,* 2019
5.	Molybdenum nanoparticles in combination with Mesorhizobium ciceri strain ST-282 and Bacillus subtilis strain Ch13	Improvement in early seedling traits, plant structural development, antioxidant mechanisms, and final harvest output in chickpea (*Cicer arietinum* L.)	Shcherbakova *et al.,* 2017
6.	Zinc, titanium, and silver-based nanoparticles	Improved seed and seedling vigour, enhanced plant morphological traits, and elevated antimicrobial properties in chilli (*Capsicum annuum* L.)	Kumar *et al.,* 2020
7.	Copper nanoparticles	Enhancement of seedling vigour and biomass in Common bean (*Phaseolus vulgaris* L.)	Duran *et al.,* 2017

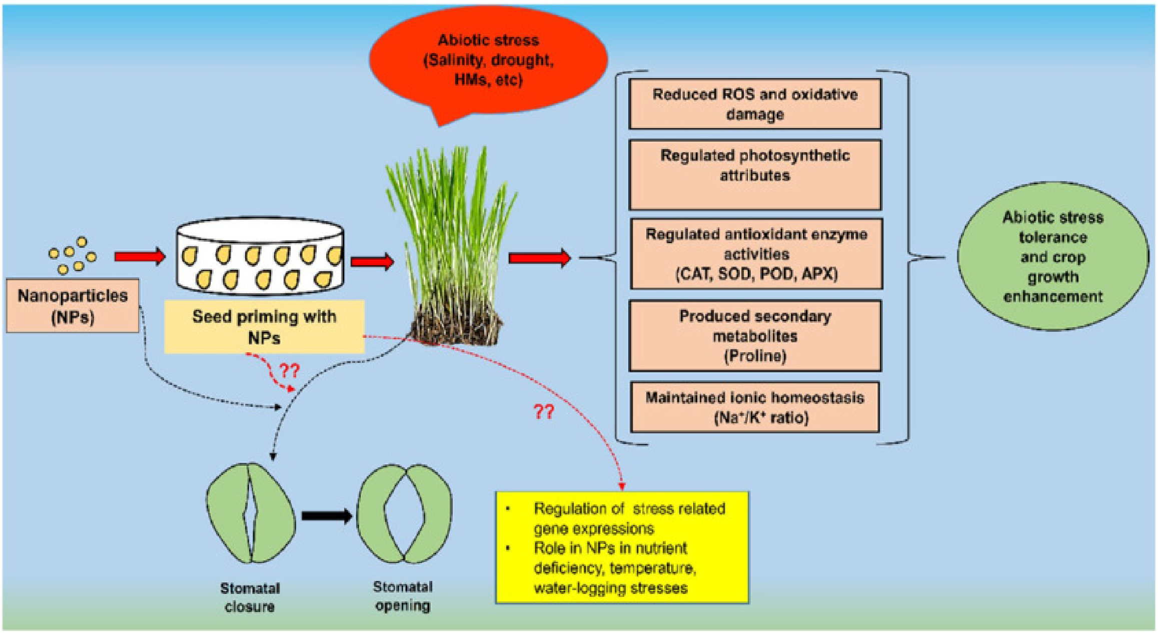

Fig. 4 : Mechanisms of stress tolerance in plants induced by nano-priming

Magneto-priming

In 1960, Krylov and Tarakanova reported on the impact of magnetic fields on plants. As compared to our unprimed seeds, magneto-primed seeds exhibit greater germination, root, vigour, and seedling biomass (Araújo *et al.,* 2016). Due to increase a-amylase and protease activity, plants originating from magneto-primed seeds, including maize and soybean *Glycine max* L., are also better able to withstand biotic (De Souza *et al.,* 2006) and abiotic stress (Anand *et al.,* 2012), less superoxide radicals are produced by soybean magneto-primed seeds (Baby *et al.,* 2011). According to de Faria *et al.* (2024), magneto-priming treatment encourages to the gradual increment in germination percentage, seedling length, water uptake, fresh and dry biomass, along with the longevity of the seed. In addition, genes related to germination and longevity such as EXP, HSP21, ABI3, HSFA3 and HSP17.6b exhibited superior expression levels response to the magneto-priming treatment. This study support to the magneto-priming as an effective method for pre-treatment to the soybean seed for enhancing the high quality of it. Further implications relate the potential of magneto-primed seeds for reducing drought stress and disease on crop productivity. The tips, adjacent to magnetic particles under the influence of a low-frequency AC magnetic field, alter structure radiation forming electrons radiate into space from an antenna to recombine with space electrons polarise molecular radiation, facilitating ion flows polarisation induction loop current ion path (Khizenkov *et al.,* 2001).

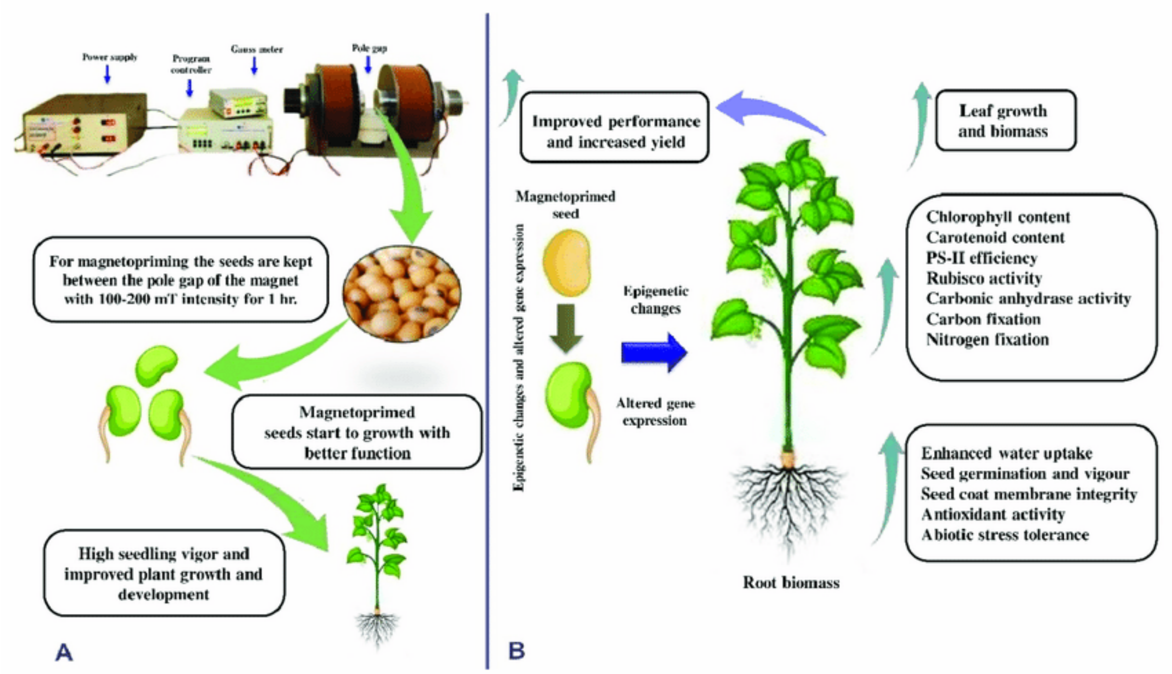

Fig. 5 (A) Process of magnetopriming begins at the seed stage and extends through to plant maturity. **(B)** This technique positively influences various stages of plant development, from germination of seed to the maximum maturity, ultimately improving photosynthetic efficiency during both normal and stress conditions.

Priming with gamma radiation

One form of ionizing radiation that is highly energetic is gamma radiation, which involves the ability to penetrate living tissues with a great degree of radiation exposure. With respect to intracellular level, gamma rays act directly on various organelles and have a direct impact particularly on nucleic acids, proteins and membranes. However, the indirect process of radiolysis of water produces reactive oxygen species (ROS). ROS generated through radiolysis within different cellular organelles and macromolecules, can cause interruption to the normal cellular functions. At lower doses, gamma rays act as a 'starting agent' by enhancing seed germination and promoting better seedling establishment under both optimal and adverse environmental conditions.

Plant growth by ionizing radiation activity of gamma rays is due to cell and tissue level effects which results in free radicals' production in the cells (Wi *et al.,* 2005). Various studies have shown that exposing seeds to low-level doses of gamma radiation can improve cell division, better germination and growth, boost enzyme activity, strengthen stress tolerance, and ultimately enhance crop productivity (Calabrese and Blain 2009; Jan *et al.,* 2012). In addition to the seeds, maize hybrid seedlings also showed the effect of gamma radiation application whereby enhancement due to the low doses (Marcu *et al.,* 2013). However, concentrations of 70 Gy caused decline in the crop performance. Alternatively, treatment of chickpea seeds with low-level doses of gamma radiation led to significantly longer root systems (Melki and Sallami, 2008). Higher gamma radiation doses inhibit the germination of seeds and plant growth whereas lower doses can be used as stimulants. Geras'kin *et al.* (2017) applied gamma radiation to the barley seeds ranging from 2 to 50 Gy and found that the greatest growth stimulation was to the seeds at 2 to 16 Gy level due to the increased activation of the enzyme.

UV irradiation priming

The magnitude of solar ultraviolet rays (UV) radiation reaching the earth's surface is rising as a result of ozone depletion in the stratosphere. Based on their wavelengths, UV radiation are categorized into three types: UVA (320-400 nm), UVB (280-320 nm), and UVC (200-280 nm). Various researchers have investigated the global effects of UV radiation on plant species at different organizational levels, ranging from individual plants to entire ecosystems. However, few studies focusing on the influence of UV exposure on seed biology remain quite controlled (Kovács and Keresztes, 2002). UVC radiation is a type of non-ionizing radiation that superficially penetrates plant tissues and potentially occurs as a disinfectant, although it is extremely harmful to the living cells. Exposure of UVC at low levels (3.6 kJ m^{-2}) triggered various structural and physiological changes in wheat, rice, maize, and cowpea (*Vigna unguiculata* L. Walp), such as enhanced germination, inflated biomass, and higher photosynthesis. UVB radiation pre-treatment (6 kJ m^{-2}) increased the activity of photosystem I and II, chlorophyll-a fluorescence, and the accumulation of the metabolites (proline, total sugars), along with both enzymes and non-enzymes antioxidants content in rice seedlings as compared to the seeds that were not primed (Thomas and Puthur, 2017). UVA radiation, the least harmful form of UV radiation, occurs about 6.3% of the incoming solar radiation (Hollósy, 2002).

There is a shortage of works which use UVA radiation as a seed invigouration technique. Radiation of UVC on wheat seeds would help return germination (Rupiasih and Vidyasagar 2016). There have been claims that the use of UV light would induce quicker seed germination and a improved germination percentage in various wheat cultivars (Sakha-94, Gemmiza9, Giza-168) attributed to an increase in seed germination percentage and germination rate (Abu-Elsaoud and Hassan, 2016).

Alleviation salinity stress on germination by seed priming

The majority of crops are much affected by the existence of saline soil, and so even with low electrical conductivity (ECe) of just 3 dS m^{-1}, the soil poses a real problem. As a result, salinity stress is a very pressing factor when it comes to crop productivity. Throughout the different stages of plant growth, germination of seed, early growth phase and seedling establishment are particularly sensitive to environmental conditions, including high salinity conditions (Ali *et al.,* 2018). Normally, seeds are sown in the top layer of soil which is more porous and thus has higher salt content while the deeper levels are retain more moisture (Esechie *et al.,* 2002). Salinity stress sometimes has the power to delay or even stop the germination of high-quality seeds, which in turn makes a crop go to waste. To realize this, the quick germs of the seeds and later sustainable young crop, are two big requires under salinity situation. So, knowledge of the scope of such water uptake genetic variation vis-a-vis salt tolerance level during the germination phase must be the prime task.

One of the most effective strategy of plant adaptation to salinity is recorded in glycophytes during the germination, and the late seedling phase is the seed priming approach. The practical and straightforward seed priming technology is a biostimulatory technique that allows the improvement of germination and the supports best seedlings development on the in the agricultural fields (Maiti and Pramanik, 2013). Recently, several research has been able to show the beneficial influence of seed priming on the germination of different crops under the saline conditions (Table 2).

Table 2 : Various types of seed priming techniques and their effects on germination under saline conditions

Crop	Treatment	Alleviating effect	Reference
Wheat (*Triticum aestivum* cv. Khirman)	Seeds primed with 50 mg/L ascorbate, 50 mM proline, 25 µM triacontanol, or 100 µM indole acetic acid for 12 hours	Treatments leads towards significant improvements in germination index and final germination rate, whereas decreasing the mean germination time under 12 dS m^{-1} salinity	Mahboob and Khan, 2019
Zea mays, *Pisum sativum*, *Lathyrus sativus*	Seeds primed with 0.2 g/L gibberellic acid (GA_3) solution for 12 hours at room temperature in the dark	GA_3 priming enhanced germination from 16.67% to 26.67% in maize, from 50% to 60% in pea, and from 73.3% to 86.67% in *L. sativus*. Mean germination time reduced by 20% under 12 dS m^{-1} salinity.	Tsegay and Andargie, 2018
Wheat (*Triticum aestivum*)	Priming of seeds with 0.5 mM spermidine for 24 h, 25 mM proline for 48 hours, or 1.5 mM silicon (K_2SiO3) for 6 hours	Germination rates increased by by 32, 18, and 17% in Spermidine, proline and K_2SiO_3 respectively enhanced the germination rate respectively under salinity stress (20 dS m^{-1})	Feghhenabi *et al.*, 2020

Melon (*Cucumis melo*)	Seeds primed with 10-50 µM melatonin for 6 hours	Germination percentage enhanced from 50% to 80% under 14 dS m^{-1} salinity due to the treatment of melatonin	Castañares and Bouzo, 2019
Cucumber (*Cucumis sativus* cv. Jinyou 1)	Seeds soaked in 0.3 mM sodium silicate (NaSi) for 36 hours	Sodium silicon priming increased rate of germination, index, and seedling vigour at 200 mM NaCl	Gou *et al.,* 2020
Limonium bicolor	Seeds priming with 80 µM salicylic acid (SA)	SA application led to significant improvements in germination rate, potential of the germination, and germination index at 200 mM NaCl	Liu *et al.*, 2019
Grain sorghum (*Sorghum bicolor* Moench	Seeds treated with 100-500 mg/L nano iron oxide (n-Fe_2O_3) for 10 hours or wet in 10 mg/L n-Fe_2O_3 for the 72 hours	Seed treatment or priming enhanced both germination speed and percentage with the 150 mM NaCl treatment	Maswada *et al.,* 2018

Conclusion

Enhanced tolerance to stress can be attained through seed priming methods, an effective approach to reduce the harmful effects of salinity and drought on plant growth and development, ultimately improving overall yield. Seed priming, which is an old-time traditional way used by western people for replenishing seeds, and treating drowned seeds were used by farmers in the olden days to achieve enhanced germination. Seed priming techniques promise a new approach to the removal of the detrimental impact of salinity and drought stress on plant growth and the overall productivity. A comprehensive awareness of the different metabolic activities that occur all over the priming intervention, as well as through germination, and the consequent related utilization of this efficient and economy technology for the maximum performance of seeds in a more resourceful way under different stress conditions. Seed priming puts cells into a preparation state in which plants adapt their cellular system to tackle the detrimental effects of the abiotic stressors, such as enduring droughts and critical temperatures. It has long been recognized that numerous seed priming methods significantly improve the crops resilience to negative environmental conditions, and that includes drought, cold, and soil salinity resistant. Also, the environmental benefits and ethical issues raised by seed priming techniques should not be overlooked as they are a sustainable and responsible strategy for global food security.

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