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# Seed Priming Methods: Application in Field Crops and Future Perspectives

Mohammad Saidur Rhaman<sup>1\*</sup>, Farjana Rauf<sup>1</sup>, Shaila Shermin Tania<sup>1</sup>  
and Mousumi Khatun<sup>2</sup>

<sup>1</sup>Department of Seed Science and Technology, Bangladesh Agricultural University,  
Mymensingh-2202, Bangladesh.

<sup>2</sup>Independent Researcher, Bangladesh.

### Authors' contributions

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

To reach in good plant stand, the life cycle of plants is faced with different critical stages such as uneven seed germination, poor and early seedling growth which ultimately results in low crop yield. It is well known that seed priming enhances germination, reduces seedling emergence time, and improves yield and yield contributing characters of plants. Seed priming is a physiological technique of seed hydration and drying to improve the metabolic process prior to germination to fasten the germination, seedling growth, and crop yield under normal, as well as different biotic and abiotic stress conditions. Many researchers have done a lot of research on seed priming in field crops to enhance the final yield. However, different priming methods and their application in field crops are poorly described. Therefore, this review paper discusses seed priming and its different methods and their application in field crops as well as future perspectives of seed priming.

**Keywords:** Germination; halo-priming; hormonal priming; hydro-priming; seed priming.

\*Corresponding author: E-mail: [saidur69bau@gmail.com](mailto:saidur69bau@gmail.com);

## 1. INTRODUCTION

Optimum seed germination is a prime condition in good stand establishment as seed is a fundamental factor in crop production. Nowadays, due to different environmental and abiotic stress, the percentage of seed germination, emergence, and vigour of seedling has been adversely affected, which ultimately results in poor crop yield. To enhance the seed germination process various physiological and non-physiological techniques are available for enhancing seed performance as well as to combat environmental constraints.

Seed priming is a low-cost effective hydration techniques to stimulate seed germination. During priming, seeds go through a physiological process, i.e. controlled hydration and drying which results in enhanced and improved pre-germinative metabolic process for rapid germination [1]. Seed priming can synchronize seed germination, and increase emergence [2,3]. Seed priming techniques have multiple benefits such as reduce the use of fertilizers, enhance crop yield by synchronized seed germination, and induce systemic resistance in plants which is both cost-effective and eco-friendly.

To obtain uniform seed development in field crops, seed priming is used, which is an economical and feasible technology. It has beneficial effects such as nutrient uptake, water use efficiency, release photo- and thermo-dormancy, maturity, and crop yield [4-6]. Seed priming has found to be beneficial for many field crops like wheat, sweet corn, mungbean, barley,

lentil, and cucumber [7]. However, many factors affect the performance of seed priming such as plant species, priming duration, temperature, priming media, and their concentration and storage conditions [8].

Although numerous data has been published by reporters on seed priming methods, however, the application of seed priming methods and their influential effects on the field crops remain poorly prescribed. This review article focuses on the different seed priming methods and their application in the field crops.

## 2. METHODS OF SEED PRIMING

To invigorate the seeds, accelerate the germination process, and alleviate the environmental stress, different seed priming methods have been developed (Fig. 1) including (i) Hydro-priming, (ii) Halo-priming, (iii) Osmo-priming, (iv) Hormone-priming, (v) Solid matrix priming and (vi) Bio-priming.

Though the choice of a priming method is important but most importantly is its efficiency which is affected by many factors and depends on the plant species. Factors like priming duration [9], priming agent [10] and oxygen supply to seed [11] have a notable effect on seeds of various crops. Following the above factors, some physical and chemical parameters such as osmotic potential, temperature, presence or absence of light, aeration, and seed condition can also effect priming and determine the germination rate and time, seedling vigour, and further plant development [12,13].

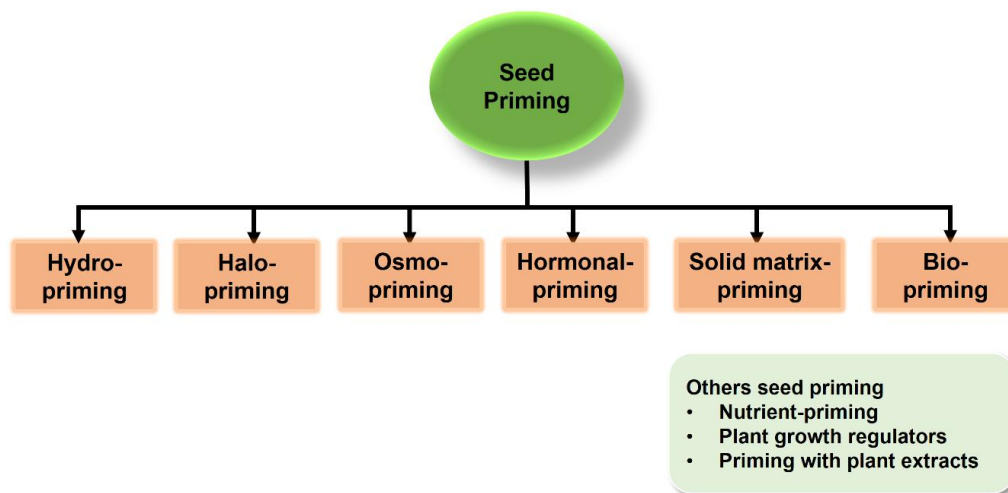


Fig. 1. Methods of seed priming

## 2.1 Hydro-priming

Hydro-priming is one of the most known and cost-effective pre-sowing seed priming method in which seeds are treated with water. This technique relies on seed soaking in water followed by re-drying to original moisture. Pill and Necker [14] reported that hydro-priming is a pre-sowing seed treatment which involves soaking the seeds in water before sowing. This methods allow the seeds to imbibe water and help to obtain the phases of germination in which pre-germination metabolic activities are started, while the latter two phases of germination are inhibited [14].

### 2.1.1 Application of hydro-priming in field crops

Poor seed germination and seedling emergence are general problems in most of the agricultural areas of Bangladesh, which ultimately results in the poor establishment of seedling and low crop yield. Hydro-priming can play a potential role to minimize this problem. Hydro priming can positively affect growth, both at the initial and later developmental stages. Yield can be affected by the growth promotion of plants. Hydro-priming improved seed germination, yield and yield contributing characteristics of okra [15]. Bastia et al. [16] reported that hydro-priming of safflower (*Carthamus tinctorius*) seed for 12 h resulted in a higher number of plants/m<sup>2</sup>, capitula per plant, grains per capitulum, 1000 seed weight, grain yield, and oil content compared to untreated seed. Similar findings were found in maize, rice, chickpea [17], and pearl millet [18] grown under dry-land conditions. Nagar et al. [19] found that hydro-priming has a pronounced effect on field emergence and seedling growth of maize crop.

Primed maize seeds (without drying) showed increased plant height and shoot dry weight [20]. Matthews and Hosseini [21] also found similar results in maize and found that hydro-primed maize seeds produced consistently and longer shoots after 5 days, than the untreated control. Thus, priming with water plays an important role in seed germination and seedling emergence in different crops. Moreover, the hydro-priming promoted germination rate and seedling emergence under salinity conditions. Roy and Srivastava [22] reported that soaking wheat kernels in water improved their germination rate under all conditions. Salt tolerance enhancement of maize [23] (*Zea mays* L.), pigeon pea [24] (*Cajanus cajan*), and acacia seeds [25] were also noticed, following hydro-priming. In some cases,

uneven hydration and non-uniform germination may take place in hydro-priming which is a disadvantage of this method. It may also not be suitable for some plant species, such as plants having a thin seed coat because of essential nutrients leakage from the seed due to rapid hydration, resulting in seed damage.

Considering these problems, different methods such as seed humidification, aerated hydration (AH), and hot water treatment have been applied for hydration of seed. Hot water treatment is effective and useful for some crops, especially for vegetable seeds. In hot water priming, certain critical temperatures are practiced for certain crops. After all, hydro-priming has been proposed as a low-cost approach, designated as on-farm seed priming by Harris [17] and involves soaking of seed in water before sowing. Hydro-priming is a simple and cost-effective technique has a very high impact in terms of improved yield [26].

Although having some disadvantages, water soaking of seed and drying before sowing can be considered as one of the easiest ways to achieve increased production.

## 2.2 Halo-priming

Halo priming is the treatment of seed with inorganic solutions such as sodium chloride (NaCl), potassium nitrate (KNO<sub>3</sub>), calcium chloride (CaCl<sub>2</sub>), and calcium sulfate (CaSO<sub>4</sub>) to improve germination. It is well-known that halo-priming plays an important role in germination, seedling emergence, and plant growth at all developmental stages of the plants.

### 2.2.1 Application of halo-priming in field crops

A number of studies have shown that there is an improvement in seed germination rate, seedling emergence, and yield contributing components of different crops in salt-affected soils in response to halo-priming. Halo-priming not only promotes seed germination, but also stimulates subsequent growth, thereby improving crop yield [27,28]. Halo-priming improved seed germination, yield and yield contributing characteristics of okra [15]. Rice seeds treated with a mixed salt solution germinated more rapidly than unprimed seeds under salt-stress conditions [28]. Bajehbaj et al. [30] reported that sunflower (*Helianthus annuus* L.) seed priming with NaCl and KNO<sub>3</sub> showed better germination percentage, compared to non-primed seeds

under salinity stress. Khan et al. [31] reported that the response of hot pepper (*Capsicum frutescens*) seeds primed with NaCl solution (1 mM) at different salinity levels 0, 3, 6 and 9 dSm<sup>-1</sup> in relation to early growth stage. The response was positive as regard as seedlings vigour and seedlings establishment under salt-stressed conditions, as against the non-primed seeds variant. Priming with NaCl and potassium chloride (KCl) removed the deleterious effects of salts [32]. Almost in all of the salinity levels, primed seeds had a higher germination rates and plumule length than control plants.

Khan et al. [31] stated that seed priming with gibberellic acid (GA<sub>3</sub>) and NaCl can result in a metabolic reaction in seeds and can improve seed germination performance and seedling establishment under salinity stress. Different biochemical changes also occurred due to halo-priming. Priming of seeds with inorganic salts may alter activity of enzymes in germinating seeds. For example, seed of muskmelon (*Cucumis melo*) soaked in KNO<sub>3</sub> solution showed enhanced activity of dehydrogenase and  $\alpha$ -amylase under low temperature. Wheat seeds primed with CaCl<sub>2</sub> reduced salinity stress by enhancing amylase activity [22]. Similarly, priming of *Pennisetum americanum* and *Sorghum bicolor* seeds with CaCl<sub>2</sub> or KNO<sub>3</sub> solution increased activity of total amylase,  $\alpha$ -amylase, and proteases under salt stress [33]. Chang-Zheng et al. [29] reported that rice seed primed with mixed-salt solution resulted in an increase in activity of  $\alpha$ -amylase,  $p$ -amylase, and root dehydrogenase, and moderate increase in the activity of shoot catalase under salt stress. Jyotsna and Srivastava [24] showed that pigeon pea seeds treated with KNO<sub>3</sub> or CaCl<sub>2</sub> generally exhibited enhanced proteins, free amino acids, and soluble sugars during germinating under salt stress. Thus, halo-priming may contribute to germination, and in better crop production.

### 2.3 Osmo-priming

Osmo-priming is when seeds are soaked in osmotic solutions at different concentrations. Based on plant species, different osmotic solutions such as sugar, polyethylene glycol (PEG), glycerol, sorbitol, and mannitol are used followed by air drying prior to sowing. Osmotic solutions contain lower water potential than pure or distilled water; these solutions permit seed imbibition and thereby activation of early phases of germination. The low water potential of the treatment solution allows partial seed hydration

so that pre-germination metabolic processes initiated [14,34,35].

#### 2.3.1 Application of osmo-priming in field crops

Osmo-priming with polyethylene glycol using an aquarium pump in wheat seeds showed improved germination and seedling vigour [36]. Like hydro-priming, osmo-priming enhances crop performance as well as seed germination under non saline or saline conditions. Italian ryegrass (*Lolium multiflorum*) and sorghum (*Sorghum bicolor*) seeds osmo-primed with 20% PEG-8000 for 2 days at 10°C, improved the germination rate in water-stressed, water-logged, cold-stress, or saline conditions [37]. In muskmelon (*Cucumis melo* L.) seeds osmo-primed with PEG-6000 showed improved dehydrogenase and amylase as well as improved germination under non-saline conditions.

Biochemical changes that play a vital role in germination and crop growth have also been reported in osmo-primed seeds of different plant species from different studies. Embryo expansion and compression of the endosperm, along with the tissue deformation were affected by osmo-priming [38]. It has been proposed that osmo-priming causes invigoration of seeds [39]. Priming with 30% PEG of wild rye (*Leymus chinensis* L.) seed for 24 h, resulted in increased activity of superoxide dismutase (SOD) and peroxidase (POX) and a rapid increase in the respiratory intensity, which were associated with an increase in germination and vigour [40]. It was reported that osmo-priming of tomato seeds increased the endo- $\beta$ -mannanase activity in the endosperm cap and decreased its mechanical restraint on the germinating embryo [41]. Different studies showed that osmo-priming affects the activity of growth regulatory enzymes like amylases, proteases, and in some cases, lipases. An increase or decrease of any of these enzymes may affect embryo growth and development. Osmo-priming with PEG also increases the activity of ATPase in the germinating seeds of peanuts. Thus, osmo-priming may contribute to germination, and in better stand establishment.

#### 2.4 Hormonal-priming

Priming of seeds using hormone solutions is referred to as hormonal-priming. Plant growth regulators used for seed imbibition during hormo-priming have direct effect on seed metabolism. Regulators such as abscisic acid, salicylic acid,

ascorbic acid, cytokinins, auxins, gibberellins, kinetin, ethylene, polyamines are commonly used for hormo-priming.

#### 2.4.1 Application of hormo-priming in field crops

The effect of hormonal priming on crops have been reported by many researchers. The exogenous application of ascorbic acid [42] and salicylic acid [43] enhanced the ability of wheat to grow under salinity stress. Wheat seed priming with kinetin has also proved to improve salt tolerance regarding growth and grain yield of wheat [32]. Iqbal and Ashraf [44] found that GA<sub>3</sub> treated spring wheat seeds increased grain yield and salt tolerance. GA<sub>3</sub> primed maize seed showed increased germination and vigour [45]. Yarnia et al. [46] reported that onion seeds invigorated with auxin, kinetin and gibberellin showed increased germination attributes. Seeds of bell pepper treated with GA<sub>3</sub> recorded higher germination, vigour and dry weight of seedlings [47]. On heavy metal polluted soil, priming of white clover seeds using GA<sub>3</sub> and PEG improved photosynthetic properties, antioxidant system, seedling emergence, and growth [48]. The effect of hormonal priming with GA<sub>3</sub> in chickpea revealed high numbers of seeds per pod and grain yield [49].

Hormonal priming has also been effective in combating drought tolerance of rice. Spermidine pretreatment [50] and polyamines-priming [10] are effective for the induction of drought tolerance in rice. Hormo-priming results in increased germination and growth in normal as well as stress condition.

#### 2.5 Solid matrix Priming

Solid matrix priming (SMP or Matri-conditioning) is a pre-seed treatment process in which seeds are mixed with known proportions of a solid material and water [51]. The seed and matrix used in SMP compete for available water. Seeds absorbing water reach an equilibrium point, which is precisely the right point for priming to occur. Afterward, seeds are separated from the matrix followed by thorough washing and drying. As a result, an optimally hydrated, metabolically active state, which is an important germination steps, can be accomplished within the seed. These include repair of membranes and/or genetic material, development of immature embryos, alteration of tissues covering the embryo, and destruction or removal of dormancy blocks. The solid medium used in the mixture

hydrate seeds slowly and simulates the natural imbibition process in the soil [35,52].

This method aims at controlling water uptake by seeds as this mixture allows the seeds to imbibe and attain a threshold moisture content, but prevents radicle emergence [51]. Materials utilized as matrices in the SMP process possess some physical and chemical features such as low matrix potential, high water holding capacity and surface area, minimal water solubility, no toxicity to seeds and ability to adhere to seed surface [53]. In SMP techniques different solid carriers are used such as vermiculite, peat moss, charcoal, compost, sand, clay, press-mud, gunny bag, synthetic calcium silicate and also some commercial offered substrate such as Celie or Microcell [52,54]. Besides, this carriers and substrates proper time duration and optimum moisture content are maintained to achieve the best priming performance [55].

#### 2.5.1 Application of solid matrix-priming in field crops

Many researchers have studied the effects of SMP on crop seeds. Crops like soybean, maize, okra and onion showed a positive effect when treated with SMP. SMP was effective in invigoration of okra and soybean by improving their germination percentage [55,56]. The effect of SMP on onion seeds showed improved seed germination rate, seedling emergence and growth under optimal and low temperature conditions [57]. In case of waxy maize seedlings, SMP priming using sand was beneficial as it increased the activities of antioxidant enzymes such as catalase (CAT), peroxidase (POX), and soluble sugar content which ultimately increased the rate of germination and seedling growth under high-salt stress conditions [58].

SMP has another advantage which is integration with biological and chemical factors that can enhance seed performance [35]. Improved stand establishment and productivity of some vegetable crops under tropical conditions were noted when gibberellins/fungicide/*Bacillus subtilis* to were included in SMP [59]. There were also reported data on improved seedling emergence and yield of okra under low temperatures when seeds were treated with mixture of a solid matrix priming and *Trichoderma viride* [60]. The SMP by using solid carrier and incorporation of solid carrier along with physical and chemical factors is becoming an integral component of agricultural practices nowadays.

## 2.6 Bio-priming

Bio-priming is an ecological approach which combines biological aspects such as seed inoculation with beneficial organism to protect the seed to control diseases and physiological aspects as hydrating seed. This new trend of seed treatment includes controlled hydration with beneficial microorganisms and enhancing the preparatory processes prior to germination [61].

The procedure of bio priming was first introduced by Callan et al. [62]. The procedural way of bio-priming is pre-soaking of seed and mixing of formulated products of bio-agent with pre-soaked seeds. Seeds were then covered with a moist jute bag (sack) to maintain high humidity followed, by incubation of seeds for 48 hrs at 25-35°C. A protective layer formed as bio-agent adheres onto the surface of the seed. This treatment technique of seed priming combines seed imbibition together with bacterial inoculation [62,63] protecting the seed from soil and seed borne pathogens [64]. Along with protecting seeds from diseases bio-priming also improves seed quality, seedling vigour [65], productivity and resistance to biotic and abiotic stress [61,66]. Seed priming is a process that involves hydration of seeds. If seeds are infected, hydration can result in a stronger microbial growth, ultimately adverse effect on plant health. Bio-priming with antagonistic microorganisms is the best way to overcome this problem [64]. Bio-priming is more effective than techniques such as pelleting and film coating regarding disease management [67].

### 2.6.1 Application of bio-priming in field crops

Bio-priming with rhizosphere bacteria has been reported for crops such as carrot [68], sweet corn [62,69] and tomato [70,71]. Raj et al. [72] reported that bio-priming of pearl millet with *Pseudomonas fluorescens* enhanced plant growth and resistance against downy mildew disease. Seeds of faba bean primed with antagonistic agents were found to be effective against root rot incidence at both pre and post-emergence stages of plant growth [73]. Germination parameters of radish seeds were improved under saline conditions as a result of bio-priming with rhizobacteria [74]. In the case of bread wheat, the productivity and bio-fortification improved because of *Pseudomonas* aided zinc (Zn) application or Zn seed priming with endophytic bacteria [75,76].

Bio-priming has been effective against damping off of cucumber (*Cucumis melo* L.) [77], pea (*Pisum sativum* L.) and soybean (*Glycine max* L.) [51]. Sivakalai and Krishnaveni [78] reported that bio-priming of pumpkin seeds with treatment combination of *Azospirillum*, phosphobacteria and *Pseudomonas fluorescens* improved the plant growth, seed yield and quality. Priming with plant growth promoting bacteria (PGPB) is a promising approach in agriculture [79,80] because of its ecological benefit, disease management capacity and fulfilling the ultimate goal of production-increasing yield. Seed priming with PGPR enhanced germination and seedling establishment [81].

## 3. FUTURE PROSPECTS OF SEED PRIMING AND ITS LIMITATS

Seed priming is a technique that can be applied to different field crops to reduce environmental stress. Being a cost-effective method, it is a practical and suitable approach to reduce the gap between potential and actual yields, even under stressful conditions. Under stress condition, seed priming is one of the best ways to reduce germination related problems, especially when crops are grown under unfavourable conditions. New and advanced priming techniques such as nano-particles, gamma-ray, magnetic ray, and UV irradiation and are being developed and applied in many field crops (Table 1).

Although seed priming has emerged as an effective seed treating tool for many crops but treating conditions and methods differ from crop to crop. However, the existing seed priming methods have some disadvantages. For instance, prolonged seed treatment during priming may cause loss of seed tolerance to desiccation [82] and some priming treatment can determine contamination with fungi and bacteria [83]. Another noticeable problem is that the longevity of primed seeds is reduced, compared to non-primed seeds [84]. Besides, seed priming with advanced methods such as priming with nanoparticles may have deleterious effects on plant, human health as well as on the environment, it is crucial to select specific priming protocols and techniques which are beneficial to plants and environment. Though, seed priming has some disadvantage it remains an environmentally safe and effective technology which can be easily adopted by not only resource-poor farmers but also different plant researcher to mitigate abiotic stress.

**Table 1. Advanced seed priming methods and their application in field crops**

Priming methods	Dose	Growth conditions	Crops and Results
Nano-particles		In field	Enhance seed germination and seedling development [85].
Gamma ray	50 Gy	Normal conditions in field	Yield and yield contributing characters of rice were increased [86].
Magnetic priming	30 mT	Water-lodging	Increased antioxidant activities in wheat [87].
UV irradiation	UVA type	Laboratory	Enhanced germination and less susceptible to root-infecting fungi in mungbean [88].

#### 4. CONCLUSION

Seed priming is an eco-friendly safe and effective technology, which enhances germination, leads to early flowering, and maturity, and makes crops more resistant to abiotic stresses. From the above discussion, it is clear that use of different priming methods has been studied on varied crops and found to be beneficial in terms of crop yield and it is suggested that seed priming is better solution against problems related to germination when seeds are grown under unfavourable conditions. However, methods of seed priming still have several limitations. All priming methods may not lead to significant germination and growth. In this regards, specific priming method selection is essential to ensure to get better germination as well as final yield. Hence, further extensive researches are required in selecting specific priming methods for different crops to ensure better yield.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

#### REFERENCES

- Dawood MG. Stimulating plant tolerance against abiotic stress through seed priming. In: *Advances in Seed Priming*. Springer, Singapore. 2018;147-183.
- Ghassemi-Golezani K, Hosseinzadeh-Mahootchy A, Zehtab-Salmasi S, Tourchi M. Improving field performance of aged chickpea seeds by hydro-priming under water stress. *International Journal of Plant, Animal and Environmental Sciences*. 2012;2:168-176.
- Dalil B. Response of medicinal plants to seed priming: A review. *International Journal of Plant, Animal and Environmental Sciences*. 2014;4(2):741-745.
- Bagheri MZ. The effect of maize priming on germination characteristics, catalase and peroxidase enzyme activity and total protein content under salt stress. *International Journal of Bioscience*. 2014;4(2):104-112. Available:<http://dx.doi.org/10.12692/ijb/4.2.104-112>
- Lara TS, Lira JMS, Rodrigues AC, Rakocevi M, Alvarenga AA. Potassium nitrate priming affects the activity of nitrate reductase and antioxidant enzymes in tomato germination. *Journal of Agricultural Science*. 2014;6(2):72. Available:<http://dx.doi.org/10.5539/jas.v6n2p72>
- Dutta P. Seed priming: New vistas and contemporary perspectives. In *Advances in Seed Priming*. Springer, Singapore. 2018;3-22.
- Sadeghian SY, Yavari N. Effect of water-deficit stress on germination and early seedling growth in sugar beet. *Journal of Agronomy and Crop Science*. 2004;190(2):138-144. Available:<https://doi.org/10.1111/j.1439-037X.2004.00087.x>
- Waqas M, Korres NE, Khan MD, Nizami AS, et al. Advances in the concept and methods of seed priming. In *Priming and Pretreatment of Seeds and Seedlings*. Springer, Singapore. 2019;11-41.
- Arif M, Jan MT, Marwat KB, Khan MA. Seed priming improves emergence and yield of soybean. *Pakistan Journal of Botany*. 2008;40(3):1169-1177.
- Farooq MA, Wahid DJ. Exogenously applied polyamines increase drought tolerance of rice by improving leaf water status, photosynthesis and membrane properties. *Acta Physiologiae Plantarum*. 2009;31:937-945. Available:<https://doi.org/10.1007/s11738-009-0307-2>

11. Nascimento WM. Muskmelon seed germination and seedling development in response to seed priming. *Scientia Agricola*. 2003;60:71-75. Available:<https://doi.org/10.1590/S0103-90162003000100011>
12. Hussain M, Farooq M, Basra SMA, Ahmad N. Influence of seed priming techniques on the seedling establishment, yield and quality of hybrid sunflower. *International Journal of Agriculture and Biology*. 2006;8:14-18.
13. Varier A, Vari AK, Dadlani M. The subcellular basis of seed priming. *Current Science*. 2010;99:450-456.
14. Pill WG, Necker AD. The effects of seed treatments on germination and establishment of Kentucky bluegrass (*Poa pratense* L.). *Seed Science and Technology*. 2001;29:65-72.
15. Tania SS, Rhaman MS, Hossain MM. Hydro-priming and halo-priming improve seed germination, yield and yield contributing characters of okra (*Abelmoschus esculentus* L.). *Tropical Plant Research*. 2020;7(1):86-93. Available:<https://doi.org/10.22271/tpr.2020.v7.i1.012>
16. Bastia DK, Rout AK, Mohanty SK, Prusty AM. Effect of sowing date sowing methods and seed soaking on yield and oil content of rainfed safflower grown in Kalahandi, Orissa. *Indian Journal of Agronomy*. 1999;44:621-623.
17. Harris D, Joshi A, Khan PA, Gothakar P, Sodhi PS. On-farm seed priming in semi-arid agriculture: Development and evaluation in corn, rice and chickpea in India using participatory methods. *Experimental Agriculture*. 1999;35:15-29.
18. Kumar A, Gangwar JS, Prasad SC, Harris D. On-farm seed priming increases yield of direct-sown finger millet in India. *International Sorghum Millets News*. 2002;43:90-92.
19. Nagar R, Dadlani PM, Sharma SP. Effect of hydro-priming on field emergence and crop growth of maize genotypes. *Seed Science Research*. 1998;26:1-5.
20. Al-Soqueer AA. The potential of seed soaking in sorghum (*Sorghum bicolor* (L) Monech) production. PhD, Thesis, University of Nottingham, UK; 2004.
21. Matthews S, Hosseini MK. Length of the lag period of germination and metabolic repair explain vigour differences in seed lots of maize (*Zea mays* L.). *Seed Science and Technology*. 2007;35:200-212. Available:<https://doi.org/10.15258/sst.2007.35.1.18>
22. Roy NK, Srivastava AK. Effect of presoaking seed treatment on germination and amylase activity of wheat (*Triticum aestivum*) under salt stress conditions. *Barley and Wheat Newsletter*; 1999.
23. Ashraf M, Rauf H. Inducing salt tolerance in maize (*Zea mays* L.) through seed priming with chloride salts: Growth and ion transport at early growth stages. *Acta Physiologiae Plantarum*. 2001;23(4):407-14. Available:<https://doi.org/10.1007/s11738-001-0050-9>
24. Jyotsna V, Srivastava AK. Physiological basis of salt stress resistance in pigeonpea (*Cajanus cajan* L.)-II. Pre-sowing seed soaking treatment in regulating early seedling metabolism during seed germination. *Plant Physiology and Biochemistry*. 1998;25:89-94.
25. Rehman S, Harris PC, Bourne WF. The effect of hardening on the salinity tolerance of Acacia seeds. *Seed Science and Technology*. 1998;26(3):743-54.
26. Ashraf M, Foolad MR. Pre-sowing seed treatment—A shotgun approach to improve germination, plant growth and crop yield under saline and non-saline conditions. *Advances in Agronomy*. 2005;88:223-71. Available:[https://doi.org/10.1016/S0065-2113\(05\)88006-X](https://doi.org/10.1016/S0065-2113(05)88006-X)
27. Eleiwa ME. Effect of prolonged seed soaking on the organic and mineral components of immature pods of soybeans. *Egyptian Journal of Botany*. 1989;32:149-60.
28. Sallam HA. Effect of some seed-soaking treatments on growth and chemical components on Faba bean plants under saline conditions. *Annals Agricultural Science*. 1999;44:159-171.
29. Chang-Zheng H, Jin H, Zhi-Yu Z, Song-Lin R, Wen-Jian S. Effect of seed priming with mixed-salt solution on germination and physiological characteristics of seedling in rice (*Oryza sativa* L.) under stress conditions. *Journal of Zhejiang University, (Agric. Life Sci.)*. 2002;28:175-178.
30. Bajehbaj AA. The effects of NaCl priming on salt tolerance in sunflower germination and seedling grown under salinity conditions. *African Journal of Biotechnology*. 2010;9(12).



- Available:<https://doi.org/10.5897/AJB10.1019>
31. Khan HA, Ayub CM, Pervez MA, Bilal RM, Shahid MA, Ziaf K. Effect of seed priming with NaCl on salinity tolerance of hot pepper (*Capsicum annuum* L.) at seedling stage. *Soil and Environment*. 2009;28(1): 81-7.
  32. Iqbal M, Ashraf M, Jamil A, Ur-Rehman S. Does seed priming induce changes in the levels of some endogenous plant hormones in hexaploid wheat plants under salt stress? *Journal of Integrative Plant Biology*. 2006;48(2),181-9. Available:<https://doi.org/10.1111/j.1744-7909.2006.00181.x>
  33. Kadiri M, Hussaini MA. Effect of hardening pretreatments on vegetative growth, enzyme activities and yield of *Pennisetum americanum* and *Sorghum bicolor* L. *Global Journal of Pure and Applied Sciences*. 1999;5:179-183.
  34. Bennett M, Fritz VA, Callan NW. Impact of seed treatments on crop stand establishment. *HortTechnology*. 1992;2: 345-349.
  35. McDonald MB. Seed priming. In: Black M, Bewley JD, (Eds). *Seed Technology and Its Biological Basis*. Sheffield Academic Press, Sheffield. 2000;287-325.
  36. Salehzade H, IzadkhanShishvan M, Chiyasi M. Effect of seed priming on germination and seedling growth of wheat (*Triticum aestivum* L.). *Journal of Biological Science*. 2009;4(5):629-31.
  37. Hur SN. Effect of osmoconditioning on the productivity of Italian ryegrass and sorghum under suboptimal conditions. *Korean Journal of Animal Sciences*. 1991;33:101–105.
  38. Liptay A, Zariffa N. Testing the morphological aspects of polyethylene glycol-primed tomato seeds with proportional odds analysis. *HortScience*. 1993;28(9):881-3. Available:<https://doi.org/10.21273/HORTS CI.28.9.881>
  39. Heydecker W, Coolbear P. Seed treatment for improved performance: Survey and attempted prognosis. *Seed Science and Technology*. 1978;5:353-425.
  40. Jie L, Gong She L, Dong Mei O, Fang L, En Hua W. Effect of PEG on germination and active oxygen metabolism in wildrye (*Leymochinensis*) seeds. *Acta Prataculturae Sinica*. 2002;11:59-64.
  41. Toorop PE, Van Aelst AC, Hilhorst HWM. Endosperm cap weakening and endo- $\beta$ -mannanase activity during priming of tomato (*Lycopersicon esculentum* cv. Moneymaker) seeds are initiated upon crossing a threshold water potential. *Seed Science Research*. 1998;8:483-491.
  42. Afzal I, Basra SM, Farooq M, Nawaz A. Alleviation of salinity stress in spring wheat by hormonal priming with ABA, salicylic acid and ascorbic acid. *International Journal of Agriculture and Biology*. 2006;8(1):23-8.
  43. Bahrani A, Pourreza J. Gibberellic acid and salicylic acid effects on seed germination and seedlings growth of wheat (*Triticum aestivum* L.) under salt stress condition. *World Applied Sciences Journal*. 2012;18(5):633-641.
  44. Iqbal M, Ashraf M. Gibberellic acid mediated induction of salt tolerance in wheat plants: Growth, ionic partitioning, photosynthesis, yield and hormonal homeostasis. *Environmental and Experimental Botany*. 2013;86:76-85. Available:<https://doi.org/10.1016/j.envexpbot.2010.06.002>
  45. Kumari N, Rai PK, Bara BM, Singh I. Effect of halo priming and hormonal priming on seed germination and seedling vigour in maize (*Zea mays* L.) seeds. *Journal of Pharmacognosy and Phytochemistry*. 2017;6(4):27-30.
  46. Yarnia M, Tabrizi EFM. Effect of seed priming with different concentration of GA3, IAA and Kinetin on Azarshahr onion germination and seedling growth. *Journal of Basic and Applied Scientific Research*. 2012;2(3):2657-2661.
  47. Yogananda DK, Vyakaranahal BS, Shekhargouda M. Effect of seed invigouration with growth regulators and micronutrients on germination and seedling vigour of bell pepper cv. California wonder. *Karnataka Journal of Agricultural Science*. 2010;17(4):811-813.
  48. Galhaut L, de Lespinay A, Walker DJ, Bernal MP, Correal E, Lutts S. Seed priming of *Trifolium repens* L. improved germination and early seedling growth on heavy metal-contaminated soil. *Water, Air, & Soil Pollution*. 2014;225(4):1905. Available:<https://doi.org/10.1007/s11270-014-1905-1>
  49. Mazed HK, Haque MN, Irin IJ, Ashraful M, Pulok I, Abdullah AH. Effect of seed priming on growth, yield and seed quality

- of chickpea (BARI chhola-6). International Journal of Multidisciplinary Research and Development. 2015;2(7):142-47.
50. Zheng M, Tao Y, Hussain S, Jiang Q, Peng S, Huang J, Cui K, Nie L. Seed priming in dry direct-seeded rice: Consequences for emergence, seedling growth and associated metabolic events under drought stress. Plant Growth Regulation. 2016;78(2):167-78. Available:<https://doi.org/10.1007/s10725-015-0083-5>
  51. Taylor AG, Harman GE, Nielsen PA. Biological seed treatments using *Trichoderma harzianum* for horticultural crops. HortTechnology. 1994;4(2):105-8.
  52. Mal D, Verma J, Levan A, Reddy MR, Avinash AV, Velaga PK. Seed priming in vegetable crops. International Journal of Current Microbiology and Applied Sciences. 2019;8(6):868-74.
  53. Khan AA. Preplant physiological seed conditioning. Horticultural Reviews. 1992;13(1):131-81.
  54. Jisha KC, Vijayakumari K, Puthur JT. Seed priming for abiotic stress tolerance: An overview. Acta Physiologiae Plantarum. 2013;35(5):1381-96. Available:<https://doi.org/10.1007/s11738-012-1186-5>
  55. Mereddy R. Solid matrix priming improves seedling vigour of okra seeds. In Proceedings of the Oklahoma Academy of Science. 2015;80:33-37.
  56. Mercado MF, Fernandez PG. Solid matrix priming of soybean seeds. Philippine Journal of Crop Science. 2002;27(2):27-35.
  57. Kępczyńska E, Piękna-Grochala J, Kępczyński J. Effects of matricconditioning on onion seed germination, seedling emergence and associated physical and metabolic events. Plant Growth Regulation. 2003;41(3):269-78. Available:<https://doi.org/10.1023/B:GROW.0000007509.94430.eb>
  58. Zhang CF, Hu J, Lou J, Zhang Y, Hu WM. Sand priming in relation to physiological changes in seed germination and seedling growth of waxy maize under high-salt stress. Seed Science and Technology. 2007;35(3):733-8.
  59. Andreoli C, de Andrade RV. Integrating matricconditioning with chemical and biological seed treatments to improve vegetable crop stand establishment and yield under tropical conditions. Seed Technology. 2002;89-99.
  60. Pandita VK, Anand A, Nagarajan S, Seth R, Sinha SN. Solid matrix priming improves seed emergence and crop performance in okra. Seed Science and Technology. 2010;38(3):665-74. Available:<https://doi.org/10.15258/sst.2010.38.3.14>
  61. Sukanya V, Patel RM, Suthar KP, Singh D. An overview: Mechanism involved in bio-priming mediated plant growth promotion. International Journal of Pure and Applied Bioscience. 2018;6(5):771-783.
  62. Callan NW, Mathre D, Miller JB. Bio-priming seed treatment for biological control of *Pythium ultimum* preemergence damping-off in sh-2 sweet corn. Plant Disease. 1990;74:368-72.
  63. Lutts S, Benincasa P, Wojtyla L, Kubala S, Pace R, Lechowska K, Quinet M, Garnczarska M. Seed priming: New comprehensive approaches for an old empirical technique. New challenges in seed biology-Basic and translational research driving seed technology. InTech Open, Rijeka, Croatia. 2016;12:1-46.
  64. Reddy PP. Bio-priming of seeds. In: Reddy PP, Editor. Recent Advances in Crop Protection. Springer. 2012;83-90.
  65. Rakshit A, Sunita K, Pal S, Singh A, Singh HB. Biopriming mediated nutrient use efficiency of crop species. In: Nutrient use efficiency: From basics to advances. Springer, New Delhi. 2015;181-191.
  66. Bisen K, Keswani C, Mishra S, Saxena A, Rakshit A, Singh HB. Unrealized potential of seed biopriming for versatile agriculture. In: Rakshit, A., Singh, H. B., and Sen, A. Nutrient Use Efficiency: From Basics to Advances (1<sup>st</sup> Ed.). Springer, New Delhi. 2015;193-206.
  67. Müller H, Berg G. Impact of formulation procedures on the effect of the biocontrol agent *Serratia plymuthica* HRO-C48 on Verticillium wilt in oilseed rape. BioControl. 2008;53(6):905-16. Available:<https://doi.org/10.1007/s10526-007-9111-3>
  68. Jensen B, Vestergaard-Povlsen F, Knudsen IMB, Funck-Jensen SD. Combining microbial seed treatment with priming of carrot seeds for control of seed borne *Alternaria* spp. In: Elad Y, Freeman S, Monte E, (Eds). Biocontrol Agents: Mode of Action and Interaction with Other

- Means of Control. Cited in IOBC WPRS Bulletin 24, Dijon: INRA. 2004;197-201.
69. Callan NW, Mathre DE, Miller JB. Field performance of sweet corn seed bio-primed and coated with *Pseudomonas fluorescens* AB254. HortScience. 1991;26(9):1163-5. Available:<https://doi.org/10.21273/HORTS CI.26.9.1163>
  70. Legro B, Satter H. Biological control of *Pythium* through seed coating and seed priming with *Trichoderma*. In: Bradford K, Hartz T, (Eds). Monterey Proceedings of the 4th National Symposium on Stand Establishment of Horticultural Crops, Monterey, California. 1995;235-7.
  71. Warren JE, Bennett MA. Bio-osmopriming tomato (*Lycopersicon esculentum* Mill.) seeds for improved stand establishment. Seed Science and Technology. 1999;27(2):489-99.
  72. Raj SN, Shetty NP, Shetty HS. Seed bio-priming with *Pseudomonas fluorescens* isolates enhances growth of pearl millet plants and induces resistance against downy mildew. International Journal of Pest Management. 2004;50(1):41-8.
  73. El-Mougy NS, Abdel-Kader MM. Long-term activity of bio-priming seed treatment for biological control of faba bean root rot pathogens. Australasian Plant Pathology. 2008;37(5):464-71. Available:<https://doi.org/10.1071/AP08043>
  74. Kaymak HÇ, Güvenç İ, Yaralı F, Dönmez MF. The effects of bio-priming with PGPR on germination of radish (*Raphanus sativus* L.) seeds under saline conditions. Turkish Journal of Agriculture and Forestry. 2009;33(2):173-9.
  75. Rehman A, Farooq M, Naveed M, Nawaz A, Shahzad B. Seed priming of Zn with endophytic bacteria improves the productivity and grain biofortification of bread wheat. European Journal of Agronomy. 2018;94:98-107.
  76. Rehman A, Farooq M, Naveed M, Ozturk L, Nawaz A. Pseudomonas-aided zinc application improves the productivity and biofortification of bread wheat. Crop and Pasture Science. 2018;69(7):659-72. Available:<https://doi.org/10.1071/CP17441>
  77. Pill WG, Collins CM, Goldberger B, Gregory N. Responses of non-primed or primed seeds of 'Marketmore 76' cucumber (*Cucumis sativus* L.) slurry coated with *Trichoderma* species to planting in growth media infested with *Pythium aphanidermatum*. Scientia Horticulturae. 2009;121(1):54-62.
  78. Sivakalai R, Krishnaveni K. Effect of bio-priming on seed yield and quality in Pumpkin cv. CO<sub>2</sub>. International Journal of Current Microbiology and Applied Sciences. 2017;6(12):85-90.
  79. Gulick BR. Plant growth-promoting bacteria: Mechanisms and applications. Scientifica. 2012;1-15.
  80. Timmusk S, El-Daim IA, Copolovici L, Tanilas T, Kännaste A, Behers L, Nevo E, Seisenbaeva G, Stenström E, Niinemets Ü. Drought-tolerance of wheat improved by rhizosphere bacteria from harsh environments: Enhanced biomass production and reduced emissions of stress volatiles. PloS One. 2014;9(5):e96086. Available:<https://doi.org/10.1371/journal.pone.0096086>
  81. Anitha D, Vijaya T, Reddy NV, Venkateswarlu N, Pragathi D, Mouli KC. Microbial endophytes and their potential for improved bioremediation and biotransformation: A review. Indo American Journal of Pharmaceutical Sciences. 2013;3:6408-17.
  82. Sliwinska E, Jendrzewiczak E. Sugar-beet seed quality and DNA synthesis in the embryo in relation to hydration-dehydration cycles. Seed Science and Technology. 2002;30(3):597-608.
  83. Wright B, Rowse H, Whipps JM. Microbial population dynamics on seeds during drum and steeping priming. Plant and Soil. 2003;255(2):631-40. Available:<https://doi.org/10.1023/A:1026055112679>
  84. Chiu KY, Chen CL, Sung JM. Effect of priming temperature on storability of primed sh-2 sweet corn seed. Crop Science. 2002;42(6):1996-2003.
  85. Ghafari H, Razmjoo J. Effect of foliar application of nano-iron oxidase, iron chelate and iron sulphate rates on yield and quality of wheat. International Journal of Agronomy and Plant Production. 2013;4(11):2997-3003.
  86. Maity JP, Mishra D, Chakraborty A, Saha A, Santra SC, Chanda S. Modulation of some quantitative and qualitative characteristics in rice (*Oryza sativa* L.) and mung (*Phaseolus mungo* L.) by ionizing radiation. Radiation Physics and Chemistry. 2005;74(5):391-4.

87. Balakhnina T, Bulak P, Nosalewicz M, Pietruszewski S, Włodarczyk T. The influence of wheat *Triticum aestivum* L. seed pre-sowing treatment with magnetic fields on germination, seedling growth, and antioxidant potential under optimal soil watering and flooding. *Acta Physiologiae Plantarum*. 2015;37(3):59. Available:<https://doi.org/10.1007/s11738-015-1802-2>
88. Siddiqui A, Dawar SH, Zaki MJ, Hamid N. Role of ultra violet (UV-C) radiation in the control of root infecting fungi on groundnut and mung bean. *Pakistan Journal of Botany*. 2011;43(4): 2221-4.

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