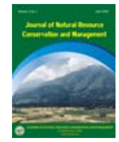
Journal of Natural Resource Conservation and Management
Vol. 1, No. 2, pp 137-150, 2020
doi: 10.51396/ANRCM.1.2.2020.137-150



Seed priming for plant stress alleviation and sustainable intensification of vegetable production

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Received : October 26, 2020
Revised : December 18, 2020
Accepted : December 20, 2020
Published : December 23, 2020

ABSTRACT

Seed priming is one of the most important methods to augment the quality of seeds, predominantly in vegetable crops as it not merely improves the seed quality but also enhances germination, improve various seedling parameters, yield, and other important traits. Nowadays, seed priming is an utmost essential practice in seed industries. There are several methods of seed priming, which comprise hydropriming, halo priming, osmopriming, solid matrix, bio priming, sand matrix priming, nutri-priming, chemo-priming, and drum priming. These techniques not merely improve the quality of seeds but they can also be used as alternative methods to mitigate the various kinds of climatic stresses. Nevertheless, more emphasis should be given on further studies to develop new methods which are cheaper, eco-friendly and readily available, for meeting the need of farmers for quality seed. This paper has been reviewed to enlighten the significance of seed priming in vegetable crops and to know the knowledge gap for further advancements.

Keywords: Priming, digital-imaging technique, electrostatic field, radicle emergence, green nanotechnology, stimulators.

INTRODUCTION

Seed priming is the method of seed treatment that elicits the pre-germination process of seed, but do not trigger the radicle emergence (Paparella *et al.*, 2015) or in simple words it can be defined as the treatment of seed before sowing or pre-sowing which hastens the germination of the seed to enhance the performance and sustain the seed quality (Kaur *et al.*, 2015; Ermis *et al.*, 2016; Saranya *et al.*, 2017). Priming can be done by means of different method and therefore is referred by different names *viz.*, Hydro-priming (soaking of seeds in water or solution followed by drying before sowing of seeds), Osmo-priming (soaking of seeds in osmotic solution), Matrix- priming (partial hydration by maintaining the aeration and moisture temperature), Halo-priming (seed treatment with salt), Nano-priming (Ye *et al*. 2020) (Â 100nm Nano microscopic particles are used for seed priming), Bio-priming (Treatment of seed with bioagents along with chemicals) (Yadav and Chandanshive, 2019), Chemo-priming (Chemical treatment with fungicides, pesticides etc. to prevent microbial contamination in seeds) , Thermo-priming (treatment of seeds at different temperature) mostly to improve the germination efficacy under hostile climatic conditions (Parera and Cantliffe, 1994; Huang *et al.*, 2002), and Drum-priming (hydration of seeds without using spent solution at the level of pre-determined humidity content by placing seeds inside the horizontally rotating drum) (Rowse, 1996). Bio-priming has also gained much prominence lately in context to increase the growth response by using biological agents. *Trichoderma* sp. has been reported in many vegetable crops such as cucumber, hot pepper, and beans (Lo and Lin, 2002). In one hand priming can trigger the enzymatic activation or synthesis to catalyze the seed storage reserves, where the hydrolase activity weakens the seed endosperm (Farooq *et al*., 2008). On the other hand the positive influence of priming are immense as it contributes to progress the antioxidant activities, seed invigoration, slowing down the rate of lipid peroxidation, and allows several metabolic processes in context to the germination occurrence (Varier *et al*., 2010). In priming application many innovative developments combined with traditional methods have been tested by researchers, worldwide (Wang *et al*. 2016). Among these nano priming is one of the modern advancements in the sector of the seed industry, and it not only helps to reduce the plant stress or use of pesticides and fertilizers etc, but also the productivity of the crops (Yo *et al*., 2020). Therefore it can be considered as a sustainable and eco- friendly approach (Acharya *et al*., 2020). Besides this, the literature cites that these nano-particles possess the ability to generate innumerable positive responses, and enhance the process of biostimulation in plants (Jordan *et al*., 2018; Maldonado *et al*., 2019; Majeed *et al*., 2020). The new era techniques and agents of priming are much costlier and utilized in large amounts because the conventional priming approaches such as hydropriming require controlled humidity conditions to be maintained at least for five days, which ultimately increase the chance of non-homogeneity in seed moisture and increase in micro-organisms incidence (Paparella, 2015; Singh *et al*., 2015). Besides this even application of electrostatic field in seed treatment has been explored (Gui *et al*., 2013). Several studies confirmed that the electrostatic fields could help to accelerate the seed biological processes (Morar *et al*., 2002; Huang *et al*., 2006).

In most of the vegetable crops, superlative and positive effects of priming were observed during abiotic stress conditions in field *viz.,* high and low temperature and water stress status (Bittencourt *et al*., 2004; Farooq *et al*., 2008). Amongst all these stresses salinity stress is the most prominent one that affects the yield, physiology and biochemistry of the Plants (Parida and Das, 2005; Munns and Tester, 2008). Seed industry is introducing new technologies for assessing various seed characteristics with high accuracy. The concept of "DIT" i.e. Digital image technology, a non-invasive technique permitting accurate and automated evaluation of seed physiological and morphological traits is being utilized by seed scientists/technologists for different purposes such as for taxonomic screening, purity, and vigor analysis (Dell'Aquila, 2009). Seed priming has proven effective in enhancing the seed vigor under different adverse weather conditions, results in speeding up and synchronization of germination and the emergence of seedlings in many vegetable and field crops (McDonald, 2000). Moreover, it has gained much attention in today's world as the most promising technique for improving seed quality. Seed priming is mostly used in seed industries to improve the product value through seed enhancement, but the procedure of priming is complex and difficult to follow as if it requires skill. Osmotic agents play an imperative role in osmopriming for proper supply of water and oxygen to seed. For example, used as osmoprimer (Poly ehthylene glycol) released ions that penetrate and accumulated inside the seed, shows nutritional imbalance and cytotoxic effects (Bujalski and Nienow, 1991). All of these priming agents are also very costly and needed in massive concentrations. However, a conventional method of seed priming, such as conventional hydro- priming entails at least 4-5 days to control humidity at an optimum level with precision (Singh *et al.,* 2015; Paparella *et al*., 2015). The method of electro-priming was firstly documented by Leong as a seed priming technique (Leong *et al*., 2016). On the other side, electro-priming has limited potential and short-lived effects hence, not used on a commercial scale (Liu *et al*., 2014). For the growth of the seed industry and to fulfil the requirement of quality seed throughout the country, there is a need for precise, smart, and efficient techniques and procedures like mechanical operation, industrial seedling, and high-quality seed supply in the vegetable seed sector. The physiological quality of the seed is one of the factors which are influenced by the pre and post harvesting practices, and also by the kind of storage conditions provided to seeds (Sano *et al*., 2016; de-Mattos and de-Carvalho, 2016; Singkaew *et al*., 2017). Seed priming is practiced in several crops as discussed in the following sections, especially focusing on the utilization of various advanced priming techniques in vegetable crops.

USE AND BENEFITS OF PRIMING IN DIFFERENT VEGETABLE CROPS

Numerous studies have been reported on priming techniques for different vegetables. A few of the important crops are covered in the following sections.

Solanaceous and Malvaceae family vegetables

The growth of seed-borne pathogens can be inhibited with the application of *Bacillus subtilis* to an acceptable level in tomato, brinjal, and okra *viz*., 95%, 92%, and 86%, respectively (Tumpa *et al*., 2016). In brinjal, aqueous garlic extract, a bio stimulant-based seed priming, augments seed germination and early growth of seedlings as confirmed with the findings of Ali *et al*., 2019. "Cold Plasma Treatment" is another priming operation practiced in okra seed imposed positive impact and enhances the growth and germination speed when seeds exposed to plasma treatment for twelve minutes on one-year-old seed in combination with zero month storability (Sehrawat *et al*., 2017). In capsicum, nano-priming with MnNPs (Manganese Nano-particles) stimulates changes in bio-molecules at molecular level and affects compositional interactions under the salt-stress conditions (Ye *et al*., 2020). With the application of carbon nanoparticles at a precise concentration, as per Lopez–Vargas *et al*. (2020), improvements in the germination, and growth were achieved, and it induced antioxidant activity. Besides this, under nematode stress conditions Jasmonic acid triggered the defense-related response in tomato plants (Bali *et al*. 2020). The influence of various osmoticum and seed priming agents showed significant benefits in solanaceous and Malvaceae family crop as presented in Table 1.

In okra, combination of humid priming for four hours along with polymer seed coating found to be significantly improved the vigor and agronomical potential of the crop (Kumar and Malarkodi, 2019). Kaur *et al*., 2015, elucidated that osmopriming for 24 hours with 5% PEG improved agronomical and biochemical parameters of the okra seeds. In addition to this, in an another method of seed priming with 0.5% single super phosphate gave a positive response for almost all traits for okra variety Sabz Pari (Shah *et al*., 2019). Bio-priming of okra seed with *Trichoderma harzianum* (NBRI 1055) in combination with 90% RDF was found to be the most expedient treatment not only in context to yield, meanwhile contributes to abate the use of fertilizers doses about 10% and 970 to 1670 KJ energy during okra production in a greenhouse (Pal and Singh, 2018).

Cucurbits

Cucurbits are frequently exposed to the incidence of numerous serious damages by seed and soil-borne pathogens, which challenges the requirement of healthy plants to attain a good harvest. Amongst these seed and soil-borne diseases, fungal incidences are most common. In addition to this, seed-borne fungi were found to be more responsible for minimizing the seed quality (Tumpa *et al*., 2018). To suppress the incidence of fungal disease number of elicitors could be utilized in the form of seed priming (Boonlertnirun *et al*., 2008). Kasote *et al*., 2019) elucidated that non-toxic Fe-NPs can significantly upsurge the non-enzymatic antioxidants and modulate the level of 12-oxo-phytodienoic acid (OPDA), and induce the "Jasmonates" linked defense response in both diploid and triploid seedlings of watermelon. To combat the seed-borne diseases *Bacillus subtilis* was found as the most satisfactory seed treating agent and showed 100% suppression of twelve fungal species in Wax gourd (Tumpa *et al*., 2016). Similarly, the authors Tumpa *et al*., 2018 elucidated that chitosan and yeast elicitors at the rate of 2000 ppm can be utilized for inhibiting the progression of seed-borne fungi in some specific cucurbits. In an another study on non-uniform, delayed, and poor seed emergence rate in bitter gourd, performed by Singh & Bassi, 2016, inferred that treatment with 1M KH_2PO_4 for 24 hours was found the best way to upsurge the rate of seed germination. More, research advancements have been summarized in the Table 2 for cucurbits.

Priming with iron oxide nanoparticles has emerges as a new concept. Kasote *et al*., 2019 tested these nano particles to be safe and non-toxic, and were synthesized using onion extract. Treatment of watermelon seeds with Fe-NPs enhanced the non-enzymatic antioxidants and defense response The cucumber seed priming with water treatment residual particles (Elkhatib *et al*., 2015) @ 200 mgL-1 improved the germination performance, particularly in cadmium stressed seeds (Elkhatib *et al*., 2020), and chlorophyll content, nutrient uptake, and photosynthesis activity could be enhanced with GA3 and KNO_3 seed priming in cucumber (Anwar *et al*., 2020). Priming of seeds with silver nanoparticles (AgNPs) enhanced seed germination, growth, yield, and quality of watermelon.

Bulb crops

Onion seeds show a major concern with respect to the vigor as detection occurs during the storage under sub-optimal conditions, but the loss could be compensated or reversed with the application of

Table 1. Influence of osmoticum/ seed priming agents and conditions on Solanaceous and Malvaceae family vegetable crops

Crop cultivar	Osmoticum/ seed priming agents and conditions	Outcome	Reference
Tomato cv. "Sirius"	Osmo-priming of seeds with PEG @ -1.25 Mpa for a period of 48 hoursSeed pelleting in a ratio of 10:3:22 seed: acacia powder: water	Higher germination percentage- Increase the mean germination time and acts as barrier that delays the seedling emergence	Soulange *et al*., 2008
Tomato cv. 'Cherry and Falcato	Osmopriming (PEG 6000 and hydration with moist vermiculite at 25°c for 24 hours)	Improvise emergence, coefficient of emergence and mean time of emergence	Amooaghaie *et al*., 2010
Tomato cv. "Chihlimbar and Siriana hybrid"	Seed primer "ASFAC stimulators	Enhances the seed vigor, germination percentage (under saline condition)	Elena *et al*., 2016
Tomato, Brinjal, and Chilli	Hormone based priming with GA_3, micronutrient treatment with KNO_3 and Na_2HPO_4	Improves seed quality parameters	Behera, 2016a and 2016b
Tomato, Brinjal	Bio-priming with *Kappaphycus alvarezii, Gracilaria corticata* (red seaweed extract) and mixture of both	Improvise germination %, germination and seedling vigor index,mean germination time ,seedling length	Patel *et al*. 2017
Tomato	Seed primedwith 0.5% of ASFAC; Seed priming with diatomite	Assured higher germination speed and early seedling vigor Enhance efficacy of seedling growth	Delian *et al*. 2018
Pepper	Seed priming	Upsurge the enzymatic activities in catalasesuperoxide Increases ascorbate peroxidase and dismutase activities	Kaya *et al*. 2010
Pepper	Seed treatment glycinebetaine	Reduce MDA contentAugmented in super oxidase dismutase enzymatic action under salinity stress	Korkmaz and Sirikci 2011
Pepper	Halo-priming with 3% KNO_3 for 40 hours (at room temperature);KNO_3 at 1%	Increased in root and shoot length, seedling vigor indexing, speed of emergence and yield specifically at field level. Maximize the germination percentage	Maiti *et al*., 2013; Dutta *et al*., 2015
Pepper	Hydro-priming for 24 hours	Maximize emergence and germination (%), germination uniformity, seed vigor and seedling emergence followed by early germination	Uche *et al*. 2016
Bell pepper	Hydro-priming and Nano-chitin	Enhance growth and emergence of seedling Reduce the meantime for germination mainly at low temperature, Reduced the incidence of fungal growth	Samarah *et al*. 2016
Pepper	Organic priming	Safest, simple, effective, easy and cheap methods, Improved seed emergence	Mavi 2016
Chilli (Pusa Jwala)	Hydropriming (PEG 6000 at -1.1 Mpa and GA_3@ 50 ppm for 24 hours at 25°C)	Enhance the performance of germination and seedling growth traits	Debbarma *et al*. 2018
Capsicum (*Capsicum chinense*) cv. "Habanero"	Osmopriming	Heightened the seedling emergence	Mavi 2018
Chilli pepper 'Piquin' (*Capsicum annum* var. *glabriusculum*)	KNO_3 and GA_3 treatment	Upsurge the hasty and uniform emergence and germination of seedlings, dormancy, germination performance, uniformity, rate of seedling establishment Diminishes the capsaicinoids content	Quintero *et al*. 2018
Okra	Partial removal of seed coat followed by soaking of seed for 24 hours	Highest seed germination percentage	Ebert *et al*. 2019

Table 2. Effect of osmoticum/ seed priming and conditions on cucurbits

Crop Cultivar	Osmoticum/ seed priming agents and conditions	Outcome	Reference
Summer squash	KNO_3 -1.27 MPa at Ec= 7 dsm^{-1} (salinity condition)	-Increase on fresh weight of seedling, root and shoot length	Gharahlar *et al.*, 2009
Bitter gourd	Osmo-priming for 12 hours	Positive effects on seed germination %, germination speed, seedling length, dry and fresh weight, and seed vigor index	Saini *et al.*, 2017
Melons	Osmotic solution of $CaCl_2$ at 25^{0}C for 3 days	-Increase germination percentage (100%) -Reduce mean germination time of one day	Castanares and Bouzo, 2018
Cucumber	Chemo-priming (Potassium nitrate (1%) and GA_3 (25 ppm) for 12 hours) Potassium nitrate (18.3 %) and GA_3 (19.8%)	-Increase germination percentage, dry matter production, root and shoot length and seed vigor index -Seed vigor index, the percent increase	Navitha *et al.*, 2019
Cucumber, Bottle gourd, wax gourd, Sweet gourd and snake gourd	Chitosan and yeast @ 2000 ppm (Elicitors) seed treatment	Suppress the growth of seed borne diseases (*A. flavus, A. niger, B. cinerea, F. moniliforme, F. oxysporum, P. exigua, R. stolonifer*, Penicillium spp., *M. phaseolina, C. lunata, Chaetomium spp., Cercospora spp., Colletotrichum spp.* and *A. alternata*	Tumpa *et al.*, 2018

various seed priming techniques as mentioned in Table 3. To increase the seed vigor and to accelerate the germination of onion seeds approaches like electrostatic field priming and hydro priming are used on a wide scale. The electrostatic field priming approach is short-lived, whereas, hydro-priming is the long time process and required precise moisture control (Zhao *et al.*, 2018). Ozden et al., 2018 discussed another approach of priming i.e. solid matrix priming, with a positive response. It enhanced the seed quality in seed lots of leek, but with more percentage of success rates in low-quality seed lots than higher ones. Arin *et al***.** (2011), inferred that the application of KNO_3 and KH_2PO_4 for six days or else until at least the primed seed of onion showed 1% of radicle emergence furthered the seedling emergence at low-temperature conditions. While, in another investigation Muhie *et al***.** (2020) interpreted that the onion seed priming with the application of vermicompost improved the activity of ascorbate peroxides, catalase, and superoxide dismutase under the temperature, drought, and salt stress conditions.

Leafy vegetables and other crops

In the context of leafy vegetables such as lettuce, seed primed with salicylic acid assuaged the cadmium toxicity (Sabanovic *et al***.**, 2018). Lettuce is considered to be the most often utilized "model plant" because lettuce is the crop that accumulates an elevated level of cadmium especially in leaves (Mensch and Baize, 2004). Considering this feature, Lettuce is frequently used to develop various kinds of strategic plans for cadmium stress tolerance and to develop techniques minimize the accumulation level in tissues of the plant (Clemens, 2006). In green leafy vegetables bio priming was found more suitable approach particularly in coriander, fenugreek and spinach. Treatment with 6% concentration of seaweed (*Sargassum wightii) extract* significantly showed positive response for seed vigor and stamina index (Hiral *et al***.** 2018)**.** Another well-known approach i.e. plasma priming has come on the notice recently. Plasma triggered modifications at the gene level in cellular transcription **(**Iranbakhsh *et al***.** 2018; Moghanloo *et al***.**, 2019; Ghasempour *et al***.**, 2020; Iranbakhsh *et al***.**, 2020) in proteomes and changed the concentrations of the hormones (Mildaziene *et al***.**, 2019; Ji *et al***.**, 2019). Several current scientific reports suggested that the plasma priming may genetically be allied to produce the long-lasting effects on plant metabolism, growth, productivity, and protection **(**Babajani *et al***.**, 2019; Sheteiwy *et al***.**, 2019; Moghanloo *et al***.**, 2019a; Moghanloo *et al***.**, 2019b; Kyzek *et al***.**, 2019; Ghasempour *et al***.**, 2020). Furthermore, the significant impacts of this priming on traits related to the germination of the seed, earliness in seedling performance, and de-contamination have been well documented (Sera, *et al***.**, 2019; Ghasempour *et al***.**, 2020). Hydro-priming showed great influence to increment the germination

Table 3. Effect of osmoticum/ seed priming and conditions on bulb crops

Crop Cultivar	Osmoticum/ seed priming agents and conditions	Outcome	Reference
Onion cv. CO onion (5)	Nutri-priming (0.5% zinc sulphate for 10 hours)	-Enhance germination, speed of germination, seed vigour and dry matter production, cell elongation and cell division at meristematic tissue	Saranya *et al.*, 2017
Onion var. "Agrifound Dark Red"	GA3 @ 100 ppm for 6 hours	-Increase germination percentage, germination speed, seedling vigor I, seedling vigor II -Decreasing mean germination time in aged seed lots	Thejeshwini *et al.*, 2018
Onion	Hydro-electrostatic hybrid priming	Maximizing the rate of seed vigor recovery	Zhao *et al.*, 2018
Onion Cultivar: Hisar onion-2, Hisar Onion-3 and Hisar Onion-4	Hydro-priming with GA3 and biofertilizers (*Azotobacter*)	Increases seed vigor and viability Maintain seed quality in one year storage	Brar *et al.*, 2019
Onion	Nano-priming with gold nano particles at 5.4ppm concentration (e.g. of Green nanotechnology nanoparticles synthesized with onion extact used as reducing agent)	Enhanced seed germination, plant height, leaf surface area, diameter and length, diameter of neck. -No toxicity symptoms develops- increased yield upto 23.9% and chlorophyll content -Lowers the pungency level	Acharya *et al.*, 2019
Onion	Seaweed extract based solid matrix priming (2:1:3 ratio of Seed: vermiculite:seaweed extract for two hours at 15°C in dark conditions)	Improved onion seed resistance under abiotic stresses and increases germination and seedling emergence rate	Demir *et al.*, 2020

percentage and speed, as well as on the seed vigor and root length in amaranthus (Moosavi *et al.*, 2009; Musa *et al.*, 2014). Alam *et al.* (2013) showed that the combination of SPP and $Na_2 Co_3$ treatment given to the spinach seed gave the best performance for most of the traits which were analyzed. More prominent studies regarding priming in leafy vegetable have been presented in Table 4.

Root crops

Priming is well known as the best pre-sowing approach in the sector of vegetable crop seeds to enhance the germination and other seed related traits (Jagosz, 2018). In case of direct-seeded vegetables, uniformity of seed emergence is a major concern to maximize the yield and quality of the produce (Pereira *et al.*, 2009). Several scientific studies have confirmed the significant impact of cluster priming in sugar beet particularly on germination, plant health, and nutrient composition of the plants. Root crops are highly vulnerable to deterioration of produce due to being in soil Sacala *et al.* (2016) established the positive response of cluster-hydro-priming on nutritional status, the concentration of phosphate photosynthetic pigments in leaves, phosphatase activity, and on root yield of sugar beet. Carrot production is vulnerable to high and low-temperature stress, and high losses occur during the germination and establishment of seedlings (Vieria *et al.*, 2005). Higher temperature exceeding 35°C hinders seed germination and harms uniformity (Nascimento and Pereira, 2007). Burks (2008) mentioned that the application of Germains XBEET priming technology resulted in a fall in cadmium baseline value from 120° to 90°. More studies related to advancements achieved in root crops with priming have been summarized in the Table 5.

Cole crops

Cabbage is one of the important crops in the cole group, and is highly sensitive to salt stress, especially at two major stages of life cycle, i.e. at germination and early growth of seedlings (zaif *et al.*, 2017). The salt stress may lead to the immense fall off in crop production, if not managed (Tester and Davenport 2003). For better outcomes in terms of incrementing the quality and yield, uniformity in

Table 4. Effect of osmoticum/ seed priming and conditions on leafy vegetables and other crops

Crop Cultivar	Osmoticum/ seed priming agents and conditions	Outcome	Reference
Spinach cv. "Bloomsdale"	Polyethylene glycol 8000 (osmocutin) at -0.6 MPa at the 15 °C temperature for 8 days	-Enhance seed stress tolerance by improving seed germination performance -Reduce water stress (at 5 °C and 20°C at the conc. of -0.8 and -1.2 MPa)	Chen *et al*. 2010
Amaranthus	Hydro-priming for 2 hours (seed soaked in water)	Improvise the production of amaranthus with highest germination percentage	Musa *et al*., 2014
Water Spinach	Partial removal of seed coat followed by soaking of seed for 24 hours	Highest seed germination percentage	Ebert *et al*., 2019
Chicory	Cold plasma seed priming method	Activates the defense mechanism of plant Leads to long term modification in growth and development of plant	Abedi *et al*., 2020
Coriander (Akash Ganga)	Hydropriming (PEG 6000 at -1.1 Mpa and GA_3 @ 50 ppm for a period of 24 hours at 25°C)	Enhance the performance of germination and seedling growth traits	Debbarma *et al*., 2018
Cluster Bean	Organic seed priming at different concentrations of cow urine (2,4,6,8, 10 and added water) and control (no treatment)	2% cow urine showed best performance for seed quality traits i.e.Germination speed, percentage of germination, length of root and shoot, vigor index I and II and production of dry matter	Tagore *et al*., 2017
Pea (*Pisum sativum* L. cv. Winner)	Hydro-priming and Osmo-priming for 12 hours	Augment the seed germination	Elocka, 2014

Table 5. Effect of osmoticum/ seed priming and conditions on root crops

Crop Cultivar	Osmoticum/ seed priming agents and conditions	Outcome	Reference
Carrot	4 and 8 days of priming treatment with PEG 6000 solution in concentration of -1.0 &1.2 Mpa	Improves seed performance and seedling emergence under abiotic stress conditions	Pereira *et al*., 2009
Carrot	Seed priming with salicylic acid 0.1mM	Boost the germination of seed under high temperature conditions	Rehman *et al*., 2020
Red beet (*Beta vulgaris* L.) varieties 'AR79 and W411'	KNO_3 and PEG 6000 at -1.0 Mpa, cluster storage of genotypes at 4°C	-Improve germination %, mean germination time, germination capacity and coefficient of velocity of abnormal seedlings (after 2 days of priming)	Jagosz, 2018
Beet root (*Beta vulgaris* L.) varieties	Nanoparticle priming with SiO_2 NPs at the conc. of 200 mg L^{-1}	Effective measure for the management of and *R. solani, M. incognita*, and *P. betavasculorum* caused diseases	Khan and Siddiqui, 2020
Suger beet 2 lots of variety "Janosik" differs in vigour level	Two patented methods:Quick Beet (QB- Patent No. P207240) and Quick Beet 1 (QB-1, Patent No. P218893)established on solid matrix priming used zeolites (water carriers)	- Minimize the unfavorable effects of pelleting on germination ability. - Priming of low vigour seed enhances the speed and germination ability. - Minimize the –ve effect ofnon-optimal humidity and low temperature on germination rate. -Both methods enhances the root yield and sugar content.	Chomontowski *et al*., 2019

seed emergence and rapid seedling establishment have been found to be most important **(**Almansouri *et al***.,** 2001). Zaif *et al***.,** 2017 described that halo-priming gave the best response for cabbage to check the adverse effect of salinity. Seed priming has been found to stimulate germination and improve early seedling growth under drought stress in case of Chinese cabbage (Yan, 2015). Several other studies have been compiled in table 6.

Table 6. Effect of osmoticum/ seed priming and conditions on Cole crops

Crop Cultivar	Osmoticum/ seed priming agents and conditions	Outcome	Reference
Chinese cabbage	H_2O, urea (200 m mol/l) and potassium nitrate (200 m mol/l)	Enhance germination percentage, seedling vigour index and potential vigour index (underdrought stress condition) Modulatesperoxidase (POD), superoxide dismutase (SOD), catalase (CAT) activities, proline and sugar level	Yan, 2015
Cabbage	KNO_3, KH_2PO_4, and KCl treated seeds	Successive increase in germination and seed vigor index (under saline condition)	Ziaf *et al.*, 2017
Broccoli	Seed primed with nitric oxide (salinity stress conditions)	-Enhanced plant growth, chlorophyll content (a), glycine betaine, total phenol content and activites of enzymes (catalase, superoxide dismutase and peroxidase) Minimize the level of H_2O_2 and MDA.	Akram *et al.*, 2020
Cabbage	$FeSO_4$ primed seeds (under NaCl stresses conditions)	Improvedthe germination rate, seedlings growth %, root and shoot length ,moisture, fresh and dry matter weight	Dilshad *et al.*, 2020
Broccoli	Solid matrix priming(SMP)	Positive impacts shown on germination vigor, vigor index and on germination indexupsurge the level of enzymatic activities of catalase and peroxidase. Increase the soluble sugar, proline and soluble protein content (in both salt stress and non-stressed conditions)	Wu *et al.*, 2019
Cauliflower	Solid matrix priming (SMP)	Constructive results shown on germination vigor, vigor index and on germination index Level up the enzymatic activities of catalase and peroxidase. Augment the soluble sugar, soluble protein and proline content (in both salt stress and non-stressed conditions)	Wu *et al.*, 2019

CONCLUSION

Specific effects of priming have been previously reported, but there has been an absence of an all-inclusive approach to appreciate priming regarding aspects related to the proteomics, metabolomics, and transcriptomics (Lutts *et al***.,** 2016). Seed priming is a precise agrotechnique which has been used, especially for vegetable crops, to improve yield and agrochemical traits by upsurging biochemical activity in seeds and seedlings. Besides conventional priming methods, several new and advanced techniques have come up such as bio-priming, hydropriming, osmo-priming, and nano-priming. Various priming methods have been standardized for a particular crop with very positive outcomes. Precise elucidation and use of procedures can improve the quality of seed, industrial supply of seeds and seedlings, and other mechanical setups, which are now in great demand in seed industries (Zhao *et al***.,** 2018). There are inadequate number of studies regarding application of green nano-priming (Acharya *et al.*, 2019) and biotechnological approaches, which must be address urgently. Seed priming industry and research needs collaboration among seed scientists, plant breeders, agronomists, and biotechnologists to further improve development and application of this important technology which conserves natural resources by improving plant responses under stressed conditions. In the coming years, it will be essential to focus on the nutritional quality improvement, resistance to various biotic and abiotic stresses through adopting eco-friendly seed priming methods. The scope is immense as seed priming may be the most important technique to counter climate change related stresses and a powerful tool to improve nutritional status, worldwide.

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