Advances in the Concept and Methods of Seed Priming

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Abstract The critical stages during the growth of crops are the uniform seed germination, early seedling growth, and uniform plant stand. Low crop yield is attributed to uneven seed germination and seedling growth. Therefore, the quality of seed can be improved through priming in addition to the field management techniques for better seed germination. Priming is a physiological technique of seed hydration and drying to enhance the pregerminative metabolic process for rapid germination, seedling growth, and final yield under normal as well as stressed conditions. The primed seeds show faster and uniform seed germination due to different enzyme activation, metabolic activities, biochemical process of cell repair, protein synthesis, and improvement of the antioxidant defense system as compared to unprimed seeds. There are many techniques of seed priming which are broadly divided into conventional methods (hydro-priming, osmo-priming, nutrient priming, chemical priming, bio-priming, and priming with plant growth regulators) and advanced methods (nano-priming and priming with physical agents). However, priming is strongly affected by various factors such as temperature, aeration, light, priming duration, and seed characteristics. This chapter highlights the priming mechanism and the available technologies as a tool for superficial seed germination and crop stand. An experiment with reference to the importance of priming toward vigor seed germination and seedling growth was conducted, and its results have been added in this chapter.

Keywords Seed priming · Germination · Antioxidant defense system · Metabolic activities · Crop growth

1 Introduction

Seed treatment before sowing is the foundation for activation of seed resources that in combination with external ingredients could contribute to the efficient plant growth and high yield. Various physiological and non-physiological techniques are available for enhancing seed performance as well as to combat environmental constraints. The physiological treatments for improving seed germination and stand establishment are composed of seed hydration techniques such as humidification, wetting, and presoaking. The other techniques for promoting germination are comprised of chemical treatments, seed inoculation with beneficial microbes, and seed coating. Seed priming is a physiological method of controlled hydration and drying to enhance sufficient pre-germinative metabolic process for rapid germination (Dawood 2018). This is one of the economic and feasible technologies for uniform seed development in most of the field crops. Other benefits include efficient nutrients uptake, water use efficiency, release photo- and thermo-dormancy, maturity, and crop yield (Hill et al. 2008; Bagheri 2014; Lara et al. 2014; Dutta 2018). However, many factors affect the performance of seed priming such as plant species, priming duration, temperature, priming media, and their concentration and storage conditions. The treated seed with a proper reagent can germinate better, for instance, seed treatment with inorganic salts (KCl and KNO_3) enhanced the germination and growth rates. The KCl improved the starch and protein contents, whereas KNO_3 increased the fruit size and quality (Singh et al. 2015a, b).

The other priming reagents involved in breaking seed dormancy are gibberellic acid (GA) and cytokinins (Assefa et al. 2010). Priming induces a set of biochemical changes such as enzyme activation, metabolism of germination inhibitors, repair of cell damages, and imbibition to promote germination (Farooq et al. 2010). Priming also modifies biochemical and physiological nature of embryo and affects the release of substances during germination phase II that activates the production of hydrolytic enzymes. These substances make high-energy compounds and essential chemicals for the germinating seedlings available (Renugadevi and Vijayageetha 2006). Therefore, the positive effects of seed priming are highly attributed to various biochemical phenomena such as improvement of the antioxidant defense system and restoration of metabolic activities through the synthesis of proteins and nucleic acids (RNA and DNA) (Di Girolamo and Barbanti 2012).

2 History of Seed Priming

Various seed treatment techniques are introduced and examined for uniform germination under different environmental conditions. Evenari (1984) reported that the efforts for improving seed germination and growth are dated back to ancient Greeks. Theophrastus (371–287 B.C.), during an investigation, observed that cucumber seeds when soaked in water result in faster and uniform germination as compared to unprimed seeds (Theophrastus, Enquiry into Plants, Book VII, I.6). Likewise, the Roman naturalist Gaius Plinius Secundus (23–79 A.D.) in his Encyclopedia reported the positive effects of presoaking of cucumber seeds in honey and water for seed germination (Gaius 1949–1954). Afterward, in 1539–1619, the French botanist Oliver de Serres reported about the seed soaked in manure water for 2 days and then dried before sowing as an effective way of seed treatment for better crop growth.

Charles Darwin tested osmo-priming on lettuce and cress seeds in seawater and observed high germination in the treated seeds as compared to nonprimed seed (Darwin 1855). The modern concept of seed priming is presented by Ells (1963), who highlighted the critical parameters related to seed treatment. He observed high germination rates when seeds were treated with a specific nutrient solution. Koehler (1967) reported that treatment with salt solution promotes RNA accumulation that, in turn, enhances other physiological process and results in high seed emergence. May et al. (1962) stated that seed drying for certain time at specific level after priming exerts beneficial effect and leads to fast germination under normal as well as stressful conditions (Berrie and Drennan 1971). Heydecker et al. (1973) used organic chemical polyethylene glycol (PEG) H–(O–CH_2–CH_2)n–OH, a high molecular weight compound, for seed pretreatment to boost germination and avoid several problems associated with salts treatment like hardening. The priming technology, so far in research and development, has been adopted as a novel technique for getting a uniform crop standby several seed and agricultural companies.

3 Phenomenon of Seed Priming

After sowing, seeds remain in the soil for a certain period to absorb water and some essential nutrients for their growth. Seed priming is a technique to reduce this time and makes the germination quickly and uniformly. In addition to hydration, priming also reduces the sensitivity of seed to external environmental factors (Afzal et al. 2016). Priming promotes seed germination under three stages such as imbibition, germination, and growth (Fig. 1). During the imbibition stage, the water uptake promotes protein synthesis and respiratory activities through messenger ribonucleic acid (mRNA). The second stage is related to the initiation of different physiological activities related to germination such as protein synthesis, mitochondria synthesis, and alteration in soluble sugars (Varier et al. 2010). The critical factor during seed priming is the controlled water uptake during the second stage, before the emergence and growth of radical from the seed coat during the last stage. The second

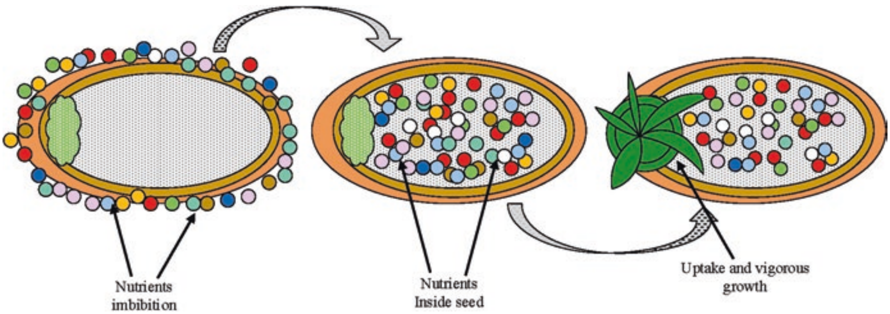

Fig. 1 General phenomenon of seed priming

stage (germination) is much sensitive to environmental factors than the third stage (Côme and Thévenot 1982). Therefore, during priming, the seeds that have passed through the second stage could germinate under variant environmental conditions as compared to unprimed seeds (Corbineau and Côme 2006).

4 Methods of Seed Priming

There are several techniques of seed priming that are broadly divided into conventional and advanced methods. The traditional techniques are comprised of hydro-priming, osmo-priming, nutrient priming, chemical priming, bio-priming, seed priming with plant growth regulators, and priming with plant extracts, whereas the advanced techniques of seed priming include seed priming through nanoparticles and priming through physical agents (Table 1). These techniques are described below.

4.1 Conventional Seed Priming Methods

4.1.1 Hydro-priming

Hydro-priming is a simple and economical technique in which seeds are soaked in water for a specific period and dried to a certain moisture level before sowing (Singh et al. 2015a, b). This technology is useful in areas with adverse environmental conditions including high heat and drought stress. Hydro-priming improves the water uptake efficiency and seed hydration under such conditions (McDonald 2000). However, it is critical to maintaining optimum humidity and temperature to avoid radical projection, as hydro-priming may result in noncontrolled water uptake (Taylor et al. 1998). The key technique of hydro-priming is "drum priming" invented by Rowse (1991). Drum priming is comprised of a drum containing seed lot connected to a boiler producing vapors. The vapors upon entering the drum condense into water droplets. During treatment, the increase in relative seed mass is measured along with strict control of the volume of the water and time required for seed hydration (Warren and Bennett 1997). Various research studies have explained that during drought stress conditions, hydro-priming increases the germination and seedling growth by 3–4 times as compared to nonpriming (Kaur et al. 2002). Likewise, Sung and Chiu (1995) reported that watermelon seeds when subjected to hydro-priming result in fast germination and seedling growth. In addition to several food crops such as *Allium porrum*, coriander, pyrethrum, and wheat, hydro-priming resulted in a uniform early germination in many desert plants like desert cacti (Dubrovsky 1996).

Table 1 The effect of conventional and advance seed priming techniques on crops growth and development

Crop	Priming solutions	Priming duration (hours)	Observations	Studies
Pepper	Marigold flowers petal extract	24	10% high seed germination 15% high seedling emergence rate Reduced the MGT up to 40% High germination index High seedling weight	Mavi (2016)
Wheat	Water, KCl, $CaCl_2$	12, 14, 24	Improved crop performance under chilling temperature Reduced time to start emergence by ~16% Reduced time to 50% germination and MET by ~17 and 33%, respectively Increase the plant height, fertile tillers, and straw yield Enhanced the grain yield by ~12	Farooq et al. (2008)
Rice	Water	24	Improved seedling growth by enhancing germination index, seedling vigor index, and germination energy Reduced mean germination time Increased panicle number(m^{-2}) Improved crop growth and final yield	Mahajan et al. (2011)
Marigold	Solution Zn and Mn	12	Enhanced the germination rate up to 93% Increased SVI by 18.5% Flower yield was increased >63% ~50% increase in essential oil production	Mirshekari et al. (2012)
Barley	Solution of Zn and P	12	Increased the germination rate from 65 to 95% 50% germination was achieved after 2 days High nutrient accumulation without affecting germination Increased the plant height, root, and shoot biomass Stimulate root growth by 27% Increased the water use efficiency by 44% under drought conditions	Ajouri et al. (2004)

(continued)

Table 1 (continued)

Crop	Priming solutions	Priming duration (hours)	Observations	Studies
Linseed	Salicylic acid, $CaCl_2$ and moringa leaf extract	12	Reduced time to 50% germination and mean germination time Enhanced the GI and final germination Increased the fresh and dry weight of root and shoot Increase in seed weight by 9.30%, biological yield by 34.16%, seed yield by 39.49%, harvest index by 4.12%, and oil contents by 13.39%	Rehman et al. (2014)
Cabbage	Urea	8	Primed seed showed high germination rate Enhanced antioxidative enzyme activity Improved soluble sugar and proline content	Yan (2015)
Tomato	Plants extracts	48	Maximum germination up to 90% Perk up seed vigor index, seedling length, and fresh and dry biomass Suppress plant disease and increased the survival rate up to 68%	Prabha et al. (2016)
Rice	Polyamine	48	Increased seed germination and seedling length Affect fresh and dry weight Enhanced net photosynthesis, proline production, water use efficiency Improved anthocyanins, soluble phenolics, and membrane properties	Farooq et al. (2009)
Mung bean	Water and polyethylene glycol	6, 12	Earlier emergence and flowering as compared to unprimed Rapid physiological maturity Increased the grain pod^{-1} by 14%, grain weight by 3.5%, and grain yield by 12%	Khan et al. (2008)
Rice	Selenium	24	Triggered germination rate and early seedling growth Greater α-amylase activity; enhanced activities of enzymatic antioxidants, peroxidase, catalase, and glutathione peroxidase; and higher soluble sugars were observed as compared to unprimed High chlorophyll content Greater membrane stability, high starch metabolism, and increased activities of antioxidant	Khaliq et al. (2015)

(continued)

Table 1 (continued)

Crop	Priming solutions	Priming duration (hours)	Observations	Studies
Fennel	Salicylic acid		Enhanced germination rate Increased seed stamina index, seedling fresh and dry weight	Farahbakhsh (2012)
Rice	Water and KH_2PO_4	24	Priming with both water and P significantly enhanced seed emergence and seedling growth Better performance for plant parameters Increased shoot biomass and root length High P concentration in shoot due to priming with P solution	Pame et al. (2015)
Peanut	ZnO nanoparticles	3	Increased seed germination rate Improved stem and root growth Increased pod yield per plant by 34% Enhanced growth and crop yield	Prasad et al. (2012)
Wheat	Silver nanoparticles	–	Increased percent germination Increased plumule and radicle length	Salehi and Tamaskani (2008)
Rice	Calcium-phosphate nanoparticles	48	Improved seedling growth Stimulate metabolites and enzymes related with antioxidative responses	Upadhyaya et al. (2017)
Rice	SiO2	6	Nanoparticles showed no toxic effect on seedling growth Improved root length, seedling dry weight, and root volume	Adhikari et al. (2013)

4.1.2 Osmo-priming

The method of osmo-priming is patented by Heydecker et al. (1973). It is a widely used commercial technique in which seeds are hydrated to a controlled level to allow pregermination metabolic activities (Halmer 2004). During the process, seeds are exposed to a controlled level of imbibition because of excess water entry to seed resulting in reactive oxygen species (ROS) accumulation as well as oxidative damage of cellular components such as proteins, lipid membranes, and nucleic acids. Osmo-priming through a delayed water entry to seed reduces the ROS accumulation and thus protects the cell from oxidative injury. Osmotica such as PEG [H-(O-CH_2-CH_2)n-OH], sugar, mannitol ($C_6H_{14}O_6$), and sorbitol ($C_6H_{14}O_6$) are added to the solution for lowering water uptake. In addition, different salts such as $NaNO_3$, $MgCl_2$, NaCl, and KNO_3 are used for osmo-priming. Singh et al. (2014) experimented on osmo-priming using cowpea. They used KNO_3 as priming solution with three levels of time durations (6, 8, and 10 h). Their results showed that in comparison to unprimed treatments, osmo-priming was proved superior in terms of all germination and growth parameters. Furthermore, osmo-priming with KNO_3 showed greater results than hydro-priming for all tested parameters. Osmo-priming is technically and financially more feasible as compared to hydro-priming, because osmo-primed seed results in quicker germination with low cost and better water conservation, thus providing a promising alternative to the farmers (Moradi and Younesi 2009). Jett et al. (1996) stated that the controlled seed hydration in osmo-priming preserves plasma membrane and causes quicker germination. However, during solution selection for osmo-priming, the morphology of seed should be considered as the semipermeable outer layers in some seeds are highly sensitive that affect the efficacy of priming (Pill 1995). The semipermeability of this outer layer is due to the presence of amorphous tissue between seed coat and pericarp that inhibits solute exchange, thus controlling priming agent and water to enter to the seed (Zhou et al. 2013). The internal osmotic equilibrium and nutritional balance of the seed will be disturbed if the solution is not properly selected according to the permeability of the seed due to the penetration of ions released from priming solution (salts) (Bradford 1995).

4.1.3 Nutrient Priming

The saturation of seeds with a certain concentration of nutrients for a specific period before sowing is known as nutrient priming (Shivay et al. 2016). Priming of crop seeds with either micro- or macronutrients enhances the nutrient substances and augments the germination, sprout (seedling) development, and water uptake efficiency. Micronutrient seed priming is a well-known technique to increase the osmosis for water regulation in seeds during the germination period (Singh 2007). For instance, seed primed with sodium molybdate dihydrate (0.02% and 0.04%) for 5 h improved the yield of mung bean (Umair et al. 2011). Likewise, macronutrient seed priming is the most effective technique (Rakshit et al. 2013). For example, potassium (K) is a mineral nutrient, and soaking of crop seeds with K increases the tolerance possibility of plant life against the different environmental stress conditions (Cakmak 2005). Grain yield of wheat and chickpea can be improved by priming with Zn solutions (Arif et al. 2007). Likewise, in moderately Zn-deficient soils such as alkaline soil, Zn priming is helpful to mimic Zn deficiency in plants (Harris et al. 2008). It also improves crop appearance, growth, yield, and nutrient absorption (Shivay et al. 2016). Chickpea seeds primed in 0.05% solution of $ZnSO_4.7H_2O$ (zinc sulfate heptahydrate) give a 19% high seeds production and have 29% more seed's Zn as compared to that of nonprimed chickpea seeds (Harris et al. 2008). Besides, mineral nutrient priming increases plants' tolerance to various environmental stress conditions (Marschner 1995). Ascorbic acid is also an essential vitamin nutrient and has been used for seed priming because it is an antioxidant in nature. Seeds primed with elevated concentrations of internal plant ascorbate retain the antioxidant capability of plants and protect them from oxidative stress damage (Zhou et al. 2009). Tavili et al. (2009) reported that seed treatment with ascorbic acid increases the germination rate of *Agropyron elongatum* grown in salt stress conditions.

4.1.4 Chemical Priming

Numerous chemicals are in use to soak a variety of crops seeds before germination. Natural and synthetic chemicals like choline, chitosan, putrescine, ethanol, paclobutrazol, $ZnSO_4$, KH_2PO_4, $CuSO_4$, and Se are used in seed priming to enhance growth and tolerance in crop plants (Jisha et al. 2013). Pretreatment of seeds with these chemicals increases crop plants growth, and plants attain resistance to various abiotic stresses. Priming of *Salvia* L. and *Capsicum annuum* L. seeds and other crop species with butenolide compound promotes seedling vitality and emergence (Demir et al. 2012). The improved seedling appearance, because of butenolide pretreatment, lessens the chance of plant pathogens' attack. Similarly, presoaking rice seeds with (1% or 5%) ethanol solution results in more rapidly and consistent germination rate and high leaf numbers (Farooq et al. 2006). Putrescine is another chemical compound that can be used for seed treatment. Soaking seeds of tobacco in this compound solution develop the cold stress tolerance at the stage of germination and seedling growth through the regulation of antioxidant system (Xu et al. 2011). Also presoaking with a paclobutrazol compound developed salt stress tolerance for *Catharanthus roseus* because of antioxidant system regulation (Jaleel et al. 2007). Shahrokhi et al. (2011) described that seed priming of turf grass with this compound in drought stress affects the plant physiology, though it is associated with the concentration of the paclobutrazol solution and the temperament of the cultivar. In addition, chitosan is a large-sized cationic polysaccharide molecule generally obtained during waste materials of seafood processing. Priming with chitosan increased disease resistance, the rate, and percentage of germination and the lipolytic activity of lipase, GA3, and indole-3-acetic acid (IAA) quantity and as well enhanced the quality of seeds for crop plants (Shao et al. 2005). Wheat seeds pretreatment in chitosan solution stimulated resistance to several diseases of crops and improved seed quality (Reddy et al. 1999). Seeds layered with chitosan increased seed germination rate and tolerance in seedlings of hybrid rice during stress condition (Ruan and Xue 2002). Maize seeds when soaked in different acidic solutions of chitosan increased the vitality of seedlings (Shao et al. 2005). Furthermore, in cold stress conditions, it enhanced the maize seeds germination velocity and hence benefited the seedlings growth (Guan et al. 2009).

4.1.5 Bio-priming

It is a seed-presoaking technique along with the inoculation of beneficial microorganisms. It combines both the biological agent (microorganisms) and physiological soaking (seed hydration) phase. Callan and Coworkers first depicted the bio-priming in 1990 for the biological management of *Pythium* pre-emergence of sh2 sweet corn. Incorporated imbibitions with a biocontrol mediator at certain temperature enhance fortification. Additionally, seed priming along with the beneficial microorganisms possibly will promote the maturity of the crop plants, mainly if the inoculated microorganisms colonize the rhizosphere of the plant and maintain plant physiology and plant growth for a longer period (Bennett and Whipps 2008). Since it is a biological approach to use both bacteria and fungi, competitors will also counter to both soil and seeds endured pathogens (Afzal et al. 2016). Callan et al. (1990) reported that bio-priming involves the varnishing of seeds by bacterial biocontrol negotiator like *Pseudomonas aureofaciens* Kluyver AB254 strain and hydrating at 23 °C for 20 h in damped vermiculite or on damped germination blotters in self-sealing plastic bags. The leakage of seeds release during the period of bio-priming could provide nutrients and strength for inoculated biocontrol agents (Wright et al. 2003). These flattering environments contribute to the migration and propagation of inoculated biocontrol mediators above the surface of the seed and assist water and nutrients uptake throughout the bio-priming period. Priming by a diverse group of beneficial microbes could not only augment the seed's nature but also boost seedling strength and capability to combat both biotic and abiotic stresses (Rakshit et al. 2015). The microbes mostly designed for bio-priming of seeds belong to *Pseudomonas* spp., *Enterobacter* spp., *Trichoderma* spp., and *Bacillus* spp. (Raj et al. 2004). For vegetable seeds, adequate bio-priming remedies were accomplished with *Trichoderma harzianum* strain, followed by *Trichoderma pseudokoningii*, *Bacillus* spp., *Gliocladium* spp., and *Pseudomonas fluorescens* (Ilyas 2006). Recently, bio-priming used as a substitute to control several soil- and seed-borne pathogens. For instance, mutual response of both *Trichoderma harzianum* and *Pseudomonas fluorescens*, when applied on pepper seeds as bio-priming agent, results in a significant growth of seedlings (Kumar et al. 2010; Reddy 2012). Various rhizobacterial inoculants are used as priming agents to control pathogenic fungal strains and to enhance crop yield. Most of the rhizospheric bacterial strains boost plant growth and physiology and thus are called plant growth-promoting rhizobacteria (PGPR) (Tonelli et al. 2011). Within the roots of tomato and rice plants, mycorrhizal fungi activate the aggregation of several transcripts and proteins that also predicts function in the plant defense mechanism (Pozo and Azcon-Aguilar 2007).

4.1.6 Priming with Plant Growth Regulators (PGR)

Seed treatment with plant growth regulators (PGR) is known to mitigate the harmful effects of several environmental stresses (Bahrani and Pourreza 2012; Jisha et al. 2013). Mendoza et al. (2002) reported that priming pepper seeds in salicylic acid protected the seedlings from adverse effects of a chill. Bell pepper primed with GA_3 (200 ppm) showed a higher rate of several physiological parameters including germination, shoot root length, and seedling vigor indices as compared to the control (Yogananda et al. 2004). In this context, indole-3-acetic acid (IAA), one of the prime auxins in plants, regulated cell division, enhanced photosynthetic activities, and activated the translocation of carbohydrates that enhance root initiation, flowering, and fruit setting and ripening (MacDonald 1997; Awan et al. 1999; Naeem et al. 2004). Similarly, gibberellins having antagonistic effects with abscisic acid (ABA) regulate seed germination and plant growth. Abu-Muriefah (2017) stated that the improved seed germination due to GA_3 priming might be due to its effect on stored food within seeds. He further described that GA_3 is known to stimulate the synthesis and production of the hydrolases resulting in the germination of seeds. Certain hydrolase enzymes are involved in seed germination process that makes the endosperm accessible to the embryo. In addition, cytokinins, ethylene, abscisic acid, and salicylic acid are some of the other plant growth promoter hormones that promote growth and regulate plant responses under various stress conditions. Similarly, certain new compounds such as KNO_3 (3%), KH_2PO_4 (2%), and PEG solutions (10%) are now being used as priming agents showing enhanced germination as compared to nonprimed seeds (Korkmaz and Korkmaz 2009; Ozbay and Susluoglu 2016).

4.1.7 Priming with Plant Extract

Allelochemicals such as phenolic compounds, terpenoids, flavonoids, saponins, alkaloids, and steroids may inhibit or stimulate plant growth (Narwal 1994). Saponins can enhance nutrient absorption as they are readily soluble in water. Alkaloids, saponins, and phenolic compounds present in the leaves of various plants are involved in the production of antioxidant activities and protect the plants against pathogens (Satish et al. 2007). Embryo and other associated structures are generally assumed to be activated by certain physiologically active substances that result in more water absorption and eventually in higher vigor index due to the development of an efficient roots system (Rangaswamy et al. 1993). Some plants are rich in saponin and alkaloids such as *Chlorophytum* leaves, while others are rich in terpenoids, steroids, flavonoids, and antiquinone such as neem leaves (Raphael 2012; Chakraborthy et al. 2014). Dawood et al. (2012) reported that amalgamation of fenugreek seeds (10%) or guava leaves or lantana leaves (20%) into the soil significantly enhanced carbohydrates and photosynthetic pigments of leaf tissues in sunflower. Similarly, the reduction in mortality and high seedling vigor in tomato was reported by priming tomato seeds with *Azadirachta*, *Chlorophytum*, and *Vinca* (Prabha et al. 2016).

4.2 Advanced Methods of Seed Priming

4.2.1 Seed Priming Through Nanoparticles

Nanotechnology utilizes nanoparticles less than 100 nm in size, and it has a promising role in transforming food production and agriculture (Fraceto et al. 2016). The excessive use of chemical fertilizers can be reduced by utilizing nanomaterials in agriculture (Upadhyaya et al. 2017). In this context, priming seeds with nanoparticles has been reported to enhance seed germination and vigor in many crops. Ghafari and Razmjoo (2013) reported that seed priming with calcium-phosphate, SiO_2, ZnO, and Ag nanoparticles enhanced germination and seedling development. The mechanism behind high seed germination in nano-priming is the greater penetration via seed coat that improves nutrient and water uptake efficiency of the seed (Dutta 2018).

4.2.2 Seed Priming Through Physical Agents

The magnetic field, UV radiation, gamma radiation, X-rays, and microwaves are some of the physical agents that are used for seed priming (Bilalis et al. 2012). Priming with magnetic field has been reported to improve germination rate, vigor, and seedling biomass as well as tolerance to various environmental stresses. The tolerances to different stresses and improved germination rate have been attributed to a reduction in reactive oxygen species (ROS) with increasing activities of antioxidant enzymes (Bhardwaj et al. 2012; Araujo et al. 2016). However, the effects of ionizing radiation such as gamma (γ) rays are dose and intensity dependent. These rays interact with cellular components directly and are reported to improve the germination at lower doses (less than 10 Gy). Certain changes in hormonal network of plant cells take place that in turn trigger the antioxidative capacity and lead to early dormancy breaking and improved germination (Qi et al. 2015). The application of mechanical waves (ultrasound) is another physical method of priming having a frequency in the range of 20–100 kHz. In ultrasound priming, mechanical pressure is imposed on seed coat that increases the seed's porosity known as acoustic cavitation and activation of enzymatic and other biological reactions due to greater water uptake in the seed. Thus, in ultrasonic priming, mass transfer of the absorbed water is enhanced that allows it to react freely with the cell embryo.

5 Factors Affecting Seed Priming

Seed priming is highly affected by various biotic and abiotic factors such as aeration, temperature, time, and seed quality. Among these, aeration is the most important and effective factor affecting seed respiration, seed viability, and seed emergence/germination (Bujalski and Nienow 1991; Heydecker et al. 1973). Heydecker and Coolbear (1977) and Bujalski et al. (1989) reported the impact of aeration in seed priming by observing enhanced germination percentage in aerated PEG solution treatment as compared to nonaerated. Similarly, the temperature is another important factor influencing the germination of seeds. Basra et al. (2005) reported that optimum temperature ranges from 15 to 30 °C for most of the seed germination. On the other hand, McDonald (2000) reported slow germination at a lower priming temperature. Wahid et al. (2008) documented a range of 15–20 °C for seed priming, and the duration of priming may extend from almost 8 h to 14 days based on plant species, osmotic solution, osmotic potential, and temperature (Finch-Savage et al. 1991). Seed quality is another important factor in seed germination, and a viable and vigorous seed is the first most necessary for seed priming (Cantliffe 1987). Other seed characteristics also play a role in seed priming and germination process. For instance, Patanè et al. (2008) reported osmo-priming with PEG solution unsuitable for sorghum seeds priming. Sorghum is rich in tannin that could be removed with the solution during treatment and hence leads to lower seed germination. In this regard, Passam et al. (1989) stated that the salt solution is effective as compared to mannitol and PEG solutions. Similarly, O'Sullivan and Bouw (1984) reported KNO_3 and K_3PO_4 as an effective priming solution in pepper seeds as compared to PEG.

6 Seed Priming: Physiological Basis and Plant Response

6.1 Occurrence of Seed Germination and Seedling Growth

In vegetable crops, high yield and growth are primarily associated with seedling health and early emergence which induces a potential to cope with various biotic and abiotic stresses. These all result in high yield and quality crops (Cantliffe 2003). Seed priming is one of the primitive techniques used to enhance early seed emergence and initiates several processes involved in seed germination (Asgedom and Becker 2001). Therefore, seed priming boosts the imbibition and metabolic processes resulting in enhanced seed germination, germination uniformity, and seedling growth and development in both normal and stress conditions (Ansari et al. 2012; Dey et al. 2014; Nayban et al. 2017). Several studies have reported that seed priming can enhance early seed emergence and growth in stress conditions as compared to untreated seeds (Bradford 1986; Chen et al. 2012). Yogananda et al. (2004) observed the increased physiological response of bell pepper treated with GA_3 and KNO_3 solution. Similarly, Yadav et al. (2011) also reported cold and salt stress tolerance in primed seeds of pepper with 100% survival. In another study, Ahmadvand et al. (2012) evaluated the effect of KNO_3-primed seeds of soybean in various cultivars and reported a significant increase in germination and seed emergence followed by increased physiological parameters like fresh weight, dry weight, root length, and shoot length.

6.2 Crop Nutrition and Yield

Crop nutrient deficiency known as hidden hunger is a global dilemma resulting in low yields and poor-quality products (Dey et al. 2014). Seed priming is an approach to provide nutrients to the seed emergence and activate various biochemical processes necessary for seed germination. This not only provides the nutrients to establish seedling growth and emergence but also helps in enrichment of grain nutrient status (Singh et al. 2015a, b) and has been proved an economical method of nutrients application as compared to soil application and has been found economical as compared to soil application (Slaton et al. 2001). Ajouri et al. (2004) reported Zn as an effective priming agent in barley (*Hordeum vulgare* L.). Another study was done to assess the Zn content of early grown radicles and coleoptiles and was found much higher up to 200 mg kg^{-1}. The study concluded that Zn might be involved in various processes during early seed development (Cakmak 2005). Additionally, higher contents of Zn may enhance seed resistance to soil-borne diseases and ensure crop growth and development (Marschner 1995). Several studies by Khan et al. (2008), Bhowmick et al. (2010), Umair et al. (2013), and Bhowmick (2013) have reported seed priming as a suitable strategy for increased crop yields. Harris (2006) reported that increased crop yield might be attributed to crop density and individual crop performance. Srivastava and Bose (2012) studied the effect of ($Mg(NO_3)_2$ and KNO_3) salts as a priming agent for rice crop and reported increased physiological response to primed seeds as compared to untreated. Similarly, Arif et al. (2008) also studied the effect of priming seeds in soybean and reported priming increased seed emergence and establishment and attributed all this to the early metabolic activities as it activates radical protrusion. However, they reported that extended priming duration might decrease crop yield and 6 h was found as a suitable duration for soybean seed priming.

6.3 Seed Priming for Stress Management

Field crops are subject to various types of biotic and abiotic stress like herbivores, pathogens attack as well as cold, heat, heavy metal, nutrient deficiency, salinity, and drought (Fedoroff et al. 2010). Among these stresses, salinity, drought, and temperature cause low growth and development (Jaleel et al. 2007; Thakur et al. 2010). These types of stress induce ROS production in a plant cell that results in cell injury and ultimately plants failure. In order to combat these ROS, plants have a self-defense mechanism that eliminates ROS species and protects plant cells from damage (Baxter et al. 2013). The intensity of stress injury depends upon various stress-related factors like stress tolerance, timing, and intensity (Niinemets 2009). Seed priming is considered one of the most promising techniques to enhance seed resistance to all these biotic and abiotic stresses (Van Hulten et al. 2006). Uchida et al. (2002) reported the importance of compounds used in seed priming technique as they alleviate the deteriorating effects of both biotic and abiotic stresses concerning plant growth. Kibinza et al. (2011) explained that germination percentages were improved by priming that was due to the considerable drop in H_2O_2 accumulation. Catalase activity was restored by priming that protects the stressed seeds from reactive oxygen species. Furthermore, Kester et al. (1997) reported that protein content in various plant tissues might be increased by seed priming via improved performance of protein synthesis system and increased production of L-isoaspartyl methyltransferase enzyme that plays an important role in repairing plant tissue proteins. Priming also enhances seed germination by enhancing the activities of protease and amylase that hydrolyze protein and starch into simple forms to make them available for the embryo (Miransari and Smith 2014). Sajedi et al. (2011) stated that ROS produced under $PbCl_2$ stress may be reduced by hormonal priming. Similarly, in another study, Pereira et al. (2009) showed improved seedling emergence by osmo-priming on carrot seed germination under extreme temperature conditions and water stress.

7 Assessment of Priming Effects on Plant Growth and Development

7.1 Seed Priming Using Compost Extract for Improving Germination Parameters

Compost tea, a liquid extract, is obtained when compost is steeped in water for a period with the aim of transferring soluble organic matters (OM), beneficial microbes, and nutrients into the solution (Mohd Din et al. 2017). The application of this microbial- and nutrient-rich tea is known for stimulating the plant's growth and soil fertility (Ahmad et al. 2017). Compost tea is prepared aerobically (aerated tea) or anaerobically (nonaerated tea); however, little evidence exists as regards which method either aerated or nonaerated is more beneficial for agricultural purposes (Amos 2017). There have been numerous studies for evaluating the potential of compost tea in suppressing the plant diseases (Mengesha et al. 2017). However, there are limited studies on the effect of compost tea on crop growth and development (Kim et al. 2015). Therefore, an assessment that was carried out aims to examine the stimulatory and inhibitory effects of compost teas on seed germination and seedling growth through a novel method of seed priming in compost tea, since no previous study has been conducted.

7.2 Preparation and Characteristics of Compost Tea

The compost used for compost teas production was prepared from food waste using an in-vessel compost bioreactor (Waqas et al. 2017). Two different types of compost teas, i.e., aerated and nonaerated, were prepared by mixing compost and water at 1:10 ratio (i.e., 1 kg dry compost in 10 L distilled water). The mixture was steeped at 25 °C for 72 h. A standard brewing method was used for steeping and extraction period during which the compost was in contact with water (Scheuerell and Mahaffee 2006). The aeration, in aerated compost tea, was maintained on a continuous basis by stirring the solution through a mechanical agitator with 80 revolutions per minute (RPM) throughout the extraction period of 72 h. The schematic diagram of the bioreactor used for making the aerated compost tea is shown in Fig. 2. Nonaerated compost tea was prepared by using a standard method of bucket fermentation (Diver 2002). This approach is referred to as the European-style or European method for compost tea preparation and dates back to hundreds of years

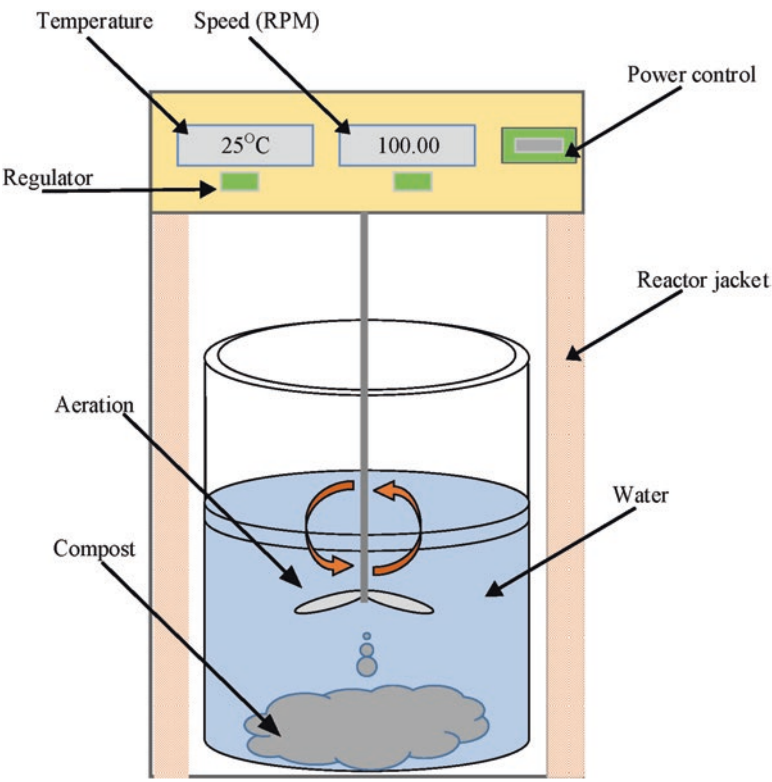

Fig. 2 Schematic diagram of reactor used for producing aerated tea

(Brinton et al. 2004). During this process, the mixture was initially stirred and then left undisturbed at 25 °C for 3 days (Weltzien 1991). After the designated steeping time, the compost extracts were filtered through a muslin cloth. Different physio-chemical characteristics of the compost tea were determined by following the standard methods of analysis, and the results are presented in Table 2. For experimentation, the compost tea was diluted using distilled water. The dilution concentrations were 0% (100% extract), 25% (75% extract, 25% water), 50% (50% extract, 50% water), 75% (25% extract, 75% water), and 100% (100% water). The 100% compost tea diluted solution was used as a control treatment for comparing the concentration effects of both compost teas.

7.3 Seed Priming and Experimental Setup

Seed priming in the compost tea was introduced by soaking the mung bean seeds in compost tea for a definite period of time. Seeds' surfaces were disinfected to avoid any bacterial or fungal contamination by imbibing them in a mixture of ethanol and

Table 2 Characteristics of compost and compost tea through aerated and nonaerated fermentation

Parameters	Compost
pH	8.02
Electrical conductivity (EC) (mS cm^{-1})	3.36
Moisture content (MC) (%)	39.31
Organic matter (OM) (%)	56.81
Ash content (%)	43.13
Carbon (%)	31.61
NH_4-N (mg kg^{-1})	168.32
NO_3-N (mg kg^{-1})	117.91
Nitrification index (NI)	1.42
	Compost tea
pH	8.94
EC (mS cm^{-1})	4.48
Ca (mg L^{-1})	17.97
K (mg L^{-1})	52.33
Mg (mg L^{-1})	19.41
Na (mg L^{-1})	173.13
Fe (mg L^{-1})	5.31
Zn (mg L^{-1})	0.14
Total Kjeldahl Nitrogen (TKN) (%)	0.47

distilled water (70:30 v/v) for 5 min and subsequently rinsing them with distilled water. Ten seeds of mung bean were then primed/soaked over dampened filter paper to assess the compost tea phytotoxicity. 20 ml of a diluted solution of each compost tea was used as a priming solution in 15 cm petri dish (Fisher brand, Fisher Scientific, Waltham MA). The petri dishes were incubated for 24 h at 25 °C in the dark and were then covered with a plastic wrapping to avoid any water loss during the priming (Mavi 2014). After priming, the seeds were washed with distilled (for consistency reasons) water and dried back to about 14% grain moisture at 36 °C in drying oven (Pame et al. 2015). A factorial experiment in a totally randomized design was used to investigate the effects of compost tea aeration methods (aerated vs. nonaerated) and priming treatments (primed vs. unprimed) on a lot of ten mung bean seeds at five different dilution concentrations of 0%, 25%, 50%, 75%, and 100%. The tea dilution at 100% solution was referred to control treatment as it contained 0% compost tea and 100% distilled water. Three replicates were used for each treatment combination. Ten seeds of mung bean were homogenously distributed on two layers of sterile Whatman™ filter paper in each petri dish. For unprimed seeds, 5 ml of each diluted solution of compost tea was applied to moisten the filter paper, whereas the petri dishes containing primed seed in compost tea were applied with only distilled water when required. The petri dishes were monitored daily, and an equal amount of tea solutions/distilled water was supplied when necessary to keep the moisture of seeds or seedlings at adequate levels. Petri dishes were incubated in a growth chamber at 27 °C for 14 days. During experimentation, different germination and growth parameters were determined through standard formulas, and the obtained data were subjected to analysis of variance (ANOVA) and least significant difference (LSD) test at 5% probability level (Steel et al. 1997).

7.4 Effects on Germination Parameters

7.4.1 Germination Rate and Germination Index (GI)

The ANOVA results indicated that compost teas' dilution and seed priming with compost tea significantly affected (state the level of significance, e.g., $\alpha = 0.05$) the seed germination and germination index. No significant differences on seed germination rate and germination index were observed for the aeration system, i.e., aerated and nonaerated teas exert the same effect on germination. The germination rate of the seeds exposed to aerated compost tea was equal to 86.3%, like nonaerated tea (86%). Among priming effects, the highest stimulation in germination rate was recorded for primed seeds, resulting in 91.6% germination, whereas that of unprimed seeds was recorded at 80.6% (Table 3). Similarly, among the tea dilution concentrations, the highest germination rate (94.2%) was observed in dilution of tea to 50%. However, a drastic reduction in germination rate was observed with increasing the tea concentration, and it was noticed that at 0% dilution (100% tea concentration), the lowest germination rate of 72.5% was observed (Table 3). Similarly, the two-way interaction between the aeration system with priming and dilution and the three-way combined interaction of aeration, dilution, and priming showed a nonsignificant effect on germination rate.

Similarly, the results showed that the maximum GI of 4.5 was estimated for primed seed, whereas the lowest GI of 2.5 was recorded for unprimed seed (Table 3). It was observed that priming had an advantageous effect in terms of seed germina-

Table 3 Effect of aeration, dilution, and priming on the germination and growth parameters of mung bean

Compost tea		G%	GI	MGT	SVI	Root length	Shoot length
Aeration	Aerated	86.3 a	3.6 a	6.1 a	221.7 a	2.4 a	5.6 a
	Nonaerated	86 a	3.4 a	5.9 a	135.3 b	1.5 b	5.2 a
Priming	Primed	91.6 a	4.5 a	4.8 b	234.1 a	2.5 a	7.1 a
	Unprimed	80.6 b	2.5 b	7.1 a	122.9 b	1.5 b	3.8 b
Dilution	0%	72.5 c	2.8 c	6.3 ab	73.2 c	0.9 c	3.3 c
	25%	84.2 b	3.3 b	6.2 ab	158.9 b	1.8 b	4.9 b
	50%	94.2 a	3.8 a	5.6 bc	241 a	2.5 a	4.7 b
	75%	88.3 ab	3.8 a	5.3 c	243.4 a	2.7 a	7.2 a
	Control	91.6 ab	3.6 ab	6.5 a	176.1 b	1.9 b	6.7 a

Means of the same category followed by different letters are significantly different at $P \leq 0.05$ level using LSD test

G% germination percentage, *GI* germination index, *MGT* mean germination time, *SVI* seed vigor index

Table 4 Interaction of aeration and dilution toward GI, SVI, and seedling growth of mung bean

Aeration	Dilution	GI	SVI	Root length	Shoot length
Aerated	0%	3.1 e	80 cd	1.05 de	3.5 d
	25%	3.5 bcde	192 b	2.2 b	5.6 bc
	50%	4 a	336 a	3.4 a	5.6 bc
	75%	3.9 ab	320.7 a	3.6 a	7.7 a
	Control	3.4 cde	179.8 b	2.1 bc	6.8 ab
Nonaerated	0%	2.5 f	66.3 d	0.9 e	3.1 d
	25%	3.2 de	125.8 bcd	1.4 cde	4.2 cd
	50%	3.6 abcd	146 bc	1.6 bcd	3.9 d
	75%	3.8 abc	166.2 b	1.9 bc	7.1 ab
	Control	3.9 ab	172.3 b	1.8 bc	6.6 ab

Means of the same category followed by different letters are significantly different at $P \leq 0.05$ level using LSD test
GI germination index, *SVI* seed vigor index

tion parameters. Similarly, the mean data for tea dilution showed that the maximum GI of 3.8 in relation to control treatment was recorded at a dilution of tea to 50%, which was similar to 75% diluted solution with GI of 3.8 (Table 3). Moreover, like germination rate, reduction in values of GI was also observed in the low diluted solutions of compost tea. The results showed that the minimum GI values of 2.8 and 3.3 were recorded at 0 and 25% diluted solutions, respectively (Table 3). In addition, the ANOVA results showed significant effects of the interaction of aeration with dilution ratios. The interaction data revealed that the maximum GI value of 4 was recorded in aerated tea at 50% dilution followed by dilution of tea to 75% with GI of 3.9 in the same tea (Table 4). Similarly, for nonaerated compost tea, the values for same tea diluted concentration (50 and 75%) were observed to be lower than aerated tea. For nonaerated compost tea, the results showed that the maximum GI value of 3.9 had been recorded for control treatment followed by 75% and 50% dilution with the GI of 3.8 and 3.6, respectively. However, for both aerated and nonaerated teas, the lowest value for GI was observed for dilution of teas to 25% and 0% (Table 4).

7.4.2 Mean Germination Time (MGT) and Seed Vigor Index (SVI)

MGT showed the rapidity of germination; hence, the lower the value of MGT, the earlier is the germination. The ANOVA results showed highly significant variation for MGT in dilution and priming of compost tea. The mean data in Table 3 revealed that the rapid germination was recorded for primed seeds with least MGT value of 4.8, whereas the higher MGT value of 7.1 for unprimed depicts the delayed seed germination. For dilution of tea, the lowest MGT value of 5.3 was noticed at 75% tea dilution. However, this value for MGT was statistically near to dilution of tea to 50% (5.6). Similarly, the maximum MGT value of 6.5 was computed for control treatment that showed low rapidity of seed germination. For aeration, the value for MGT in aerated tea was 6.1, which was statistically similar to the MGT value of 5.9

for nonaerated tea (Table 3). This nonsignificant difference showed that the aeration system did not affect MGT of the tested seeds. The overall results revealed that priming reduced the MGT by 31.2% in comparison with unpriming. Similarly, compared to control, the solution containing 25% and 50% compost tea reduced the MGT by 18.4 and 12.9%, respectively.

SVI expressed the level of seed performance and activity during the germination and seedling emergence. It was found that SVI was significantly affected by aeration, tea dilution, and priming. Moreover, the results indicated that the two-way interaction between aeration with dilution and priming also had significant effects toward SVI. The results showed that among the aeration systems, the utmost SVI of 221.7 was recorded for aerated tea, leaving behind nonaerated tea with the value of 135.3 (Table 3). Similarly, among the priming effects, the highest values were recorded for primed seed that was 234.1 whereas the least values (122.9) were estimated for unprimed seeds. In addition, compost tea dilution showed high variation toward SVI. The highest SVI (243.4) was observed for dilution of tea to 75% that was statistically like 50% diluted tea (241), whereas the least SVI (73.2) was recorded for dilution of tea to 0% (Table 3). Furthermore, the mean data for the two-way interaction of aeration with dilution showed that the maximum SVI (336) was observed for aerated tea diluted at 50% (Table 4). This value was found statistically similar to 75% tea dilution with the SVI value of 320.7. Similarly, the lowest SVI of 66.3 was recorded at 0% tea dilution in nonaerated (Table 4). Furthermore, the mean data for the interaction of priming with dilution showed that the utmost values for SVI (353.5) were observed for primed seeds with a dilution of tea to 50% followed by 25 and 75% diluted tea solutions with SVI values of 272 and 270.3, respectively (Table 5), whereas the minimum SVI (28.2 and 45.8) was noticed for dilution of tea to 0 and 25% in unprimed seeds, respectively (Table 5). The combined interaction of aeration, dilution, and priming showed that highest SVI (526.7) was noticed in primed seeds with the dilution of aerated compost tea to 50%. Similarly, the second highest peak value of 370.7 for SVI also observed for primed seed with aerated tea at tea dilution

Table 5 Interaction of priming and dilution toward SVI and seedling growth of mung bean

Priming	Dilution	SVI	Root length	Shoot length
Primed	0%	118.2 d	1.5 e	6 c
	25%	272 b	2.9 ab	8.6 a
	50%	353.5 a	3.6 a	7.7 ab
	75%	270.3 b	2.8 bc	7.7 ab
	Control	156.7 cd	1.6 de	5.4 c
Unprimed	0%	28.2 e	0.4 f	0.6 d
	25%	45.8 e	0.6 f	1.3 d
	50%	128.5 d	1.4 e	1.8 d
	75%	216.5 bc	2.7 bc	6.2 bc
	Control	195.5 c	2.3 cd	9.1 a

Means of the same category followed by different letters are significantly different at $P \leq 0.05$ level using LSD test
SVI seed vigor index

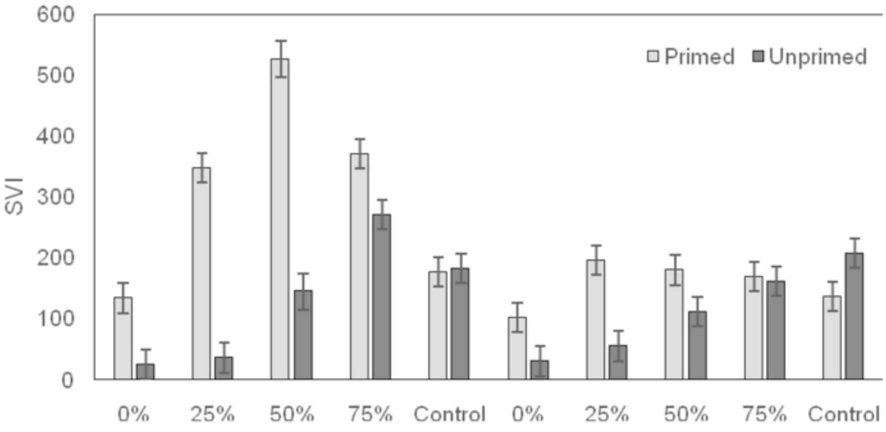

Fig. 3 Interaction of aeration, dilution, and priming on seed vigor index of mung bean. Vertical bars represent ± standard error of the mean

to 75%. Conversely, the lowest SVI (25.7 and 30.7) was noticed for unprimed seeds at 0% tea dilution in both the aerated and nonaerated teas, respectively (Fig. 3).

7.4.3 Effects on Root and Shoot Length

The tea dilution and priming and their combined interaction affected significantly (a = 0.05) mung bean root and shoot length. However, the effect of aeration on the shoot length was observed nonsignificant. The results showed that the maximum mean root length (2.4 cm) was recorded for aerated tea. Similarly, the mean data for priming depict that the utmost root (2.5 cm) and shoot length (7.1 cm) were observed for primed seed, whereas for unprimed seed, the observed root and shoot length were 1.5 and 3.8 cm, respectively (Table 3). In addition, the mean data for compost tea dilution showed that the maximum root length (2.7 and 2.5 cm) was observed for dilution of teas to 75 and 50%, whereas the highest shoot length (7.2 cm) was noticed for dilution of tea to 75%. Correspondingly, the minimum root (0.9 cm) and shoot length (3.3 cm) was estimated for dilution of tea to 0% (Table 3). The interaction of aeration with dilution showed that among the aerated and nonaerated compost teas, the highest root length (3.6 cm) was recorded for tea dilution to 75% that was statistically similar to dilution of tea to 50% (3.4 cm) (Table 4). Similarly, the highest shoot length (7.7 cm) was recorded in aerated compost tea at 75% dilution, whereas the least values for root and shoot length (0.9 and 3.1 cm) were observed in nonaerated compost tea at 0% dilution followed by 25% dilution of the same tea (Table 4). As the ANOVA results also showed significant differences among the interaction between priming and tea dilution, the utmost root length (3.6 cm) was observed for primed seed in compost tea at 50% dilution, whereas for shoot length, the maximum value (8.6 cm) was recorded at 25% dilution. The bare minimum root and shoot length (0.4 and 0.6 cm) were calculated for unprimed seeds treated with compost tea at 0% dilution followed with 25% dilution in the same tea (Table 5).

The combined interaction of aeration, tea dilution, and priming revealed that the maximum seedling root length (5.3 cm) was recorded for primed seed at 50% diluted solution of the aerated tea (Fig. 4). Similarly, the highest shoot length of 10 and 9.2 cm was recorded for seeds primed with dilution of aerated tea to 25 and 50%, respectively (Fig. 5), whereas the maximum inhibition in root and shoot length was resulted by 100% tea concentration (0% dilution). The recorded root and shoot length at the respective 0% dilution were 0.4 and 0.73 cm in aerated and 0.5 and 0.6 cm in nonaerated compost tea (Figs. 4 and 5).

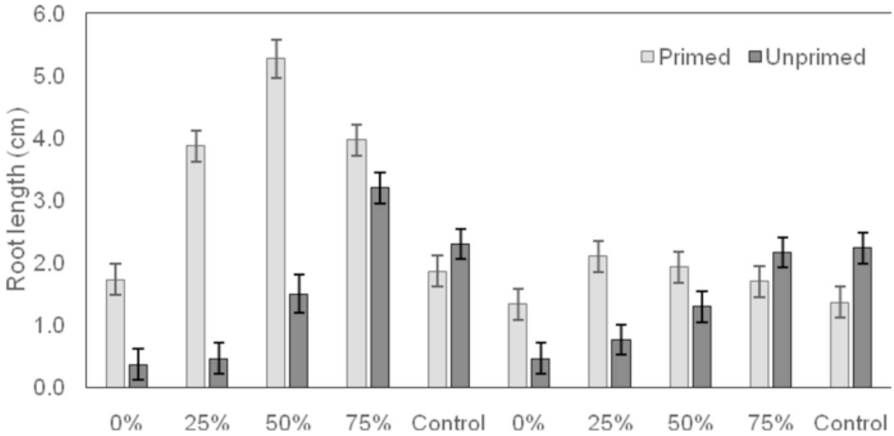

Fig. 4 Interaction of aeration, dilution, and priming on root length of mung bean. Vertical bars represent ± standard error of the mean

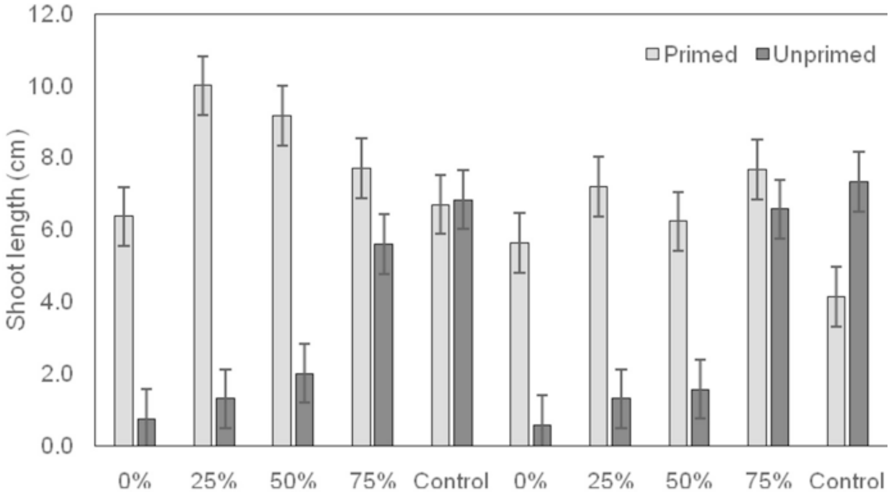

Fig. 5 Interaction of aeration, dilution, and priming on shoot length of mung bean. Vertical bars represent ± standard error of the mean

8 Limitations and Perspective in Seed Priming Technology

Seed priming has been developed as a promising technology for superficial crop stand in a variety of environmental conditions. However, many protocols such as seed desiccation (redrying) after priming may affect different physiochemical process which reduces seed longevity and viability (Heydecker and Gibbins 1977; Halmer 2004). Other conditions for posttreatment such as storage temperature, air composition, and moisture also negatively affect seed viability (Schwember and Bradford 2005). Similarly, the prolonged seed treatment during priming may also cause loss of seed tolerance to desiccation (Sliwinska and Jendrzejczak 2002). Priming itself in certain circumstances may also cause different problems. For instance, all priming protocols may not lead to significant germination and growth where inappropriate priming conditions may cause degradation of the protective proteins (Capron et al. 2000). Hence, it is critical to select specific priming protocol for different plants about germination and growth in different environmental conditions. Thus, for filling the gap and successful application of priming technology, detailed studies focusing on treatment technologies, gene expressions, and molecular mechanisms need to be fully explored (Araujo et al. 2016). Correspondingly, the advanced methods of seed priming such as priming with nanoparticles may also have deleterious effects on environment, plant, and human health. In this regard, solid studies need to be performed for resolving the impact of nanomaterials when enter the food chain by using them in agriculture. Extensive researches are still required for each priming technology in terms of optimal dose, exposure time, and dose rate that could affect plant growth and development.

9 Conclusions

Seed priming is the physiological process of controlled seed hydration to enhance sufficient pregerminative metabolic process, efficient nutrient uptake and water use efficiency, breaking dormancy, timely maturity, and crop yield. During imbibition, the water uptake promotes protein synthesis and respiratory activities by using extant messenger ribonucleic acid (mRNA) with the initiation of different physiological activities related to germination. This technology has been found to be the most feasible and economical for uniform seed emergence in most of the field crops. There are many well-developed seed-priming techniques such as hydro-priming, osmo-priming, nutrient priming, chemical priming, bio-priming, priming with plant growth regulators, priming with plant extracts, seed priming through nanoparticles, and priming through physical agents. However, priming technology still has several limitations. The prolonged seed treatment during priming may cause loss of seed tolerance to desiccation that reduces seed viability. Similarly, all priming protocols may not lead to significant germination and growth where inappropriate priming conditions may cause degradation in the protective proteins. Hence, extensive researches are required in selecting specific priming protocol for different plants regarding germination and growth under various environmental conditions.

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