Endophytes and seed priming: Agricultural applications and future prospects

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Abstract

In the current scenario of climate change, numerous strategies have been employed in the area of sustainable agriculture or plant science to generate plants which can withstand various types of biotic and abiotic stresses. Currently a range of biotic and abiotic stresses such as cold, draught, salinity, water deficit, or extreme pH is present that directly or indirectly influence the germination, growth and productivity of crops. Seed priming has been developed as a crucial method to germinate the seed or increase plants resistance against various biotic and abiotic stresses. Seed priming is the induction of a particular physiological state in plants by the treatment of natural and synthetic compounds to seeds before germination.

Seed priming with microbial inoculum, termed as 'bio-priming', involves the application of beneficial microbes, such as bacteria, fungi actinomycetes, to seed that enhance the uniformity, establishment and growth of various crops. Seed bio-priming allows the bacteria to enter/adhere to the seeds and also acclimatization of microbes in the prevalent conditions. Seed priming with the use of endophytic microbial strains appears as more beneficial or stable than rhizospheric microbial strains due to better colonization adaptability and suitability under biotic and abiotic stress conditions.

Keywords: Abiotic stress, Bio-priming, Endophytes, Diazotrophy, Rhizophagy cycle, Seed priming, Sustainable agriculture

Introduction

The continuous rise in global population is one of the most severe problems that influence agriculture sectors and creates pressure to researchers as well as farmers to meet human demand for food in limited resources of land and changing climatic conditions. In this context improved quality of seed to fulfill the higher demand of agriculture has been recognized as a major challenge globally. Slower growth of developing seedlings under various abiotic factors (harsh environmental conditions) or biotic factors (pathogenic microorganisms) limits the growth and yield of crops; development of techniques for fast and homogeneous growth of seeds could be a sustainable approach for better agricultural productivity (Osburn and Schroth 1989). In this aspect, improving the quality and germination and establishment of seed through 'seed priming' is a sustainable approach to enhance yields and performance of plants (McDonald 2000). Interestingly, primed seeds have been demonstrated to withstand the numbers of abiotic and biotic stresses leading to enhanced seed emergence along with crop productivity.

The term 'seed priming' first proposed by Heydecker et al. (1973) was described as an effective technology for the enhancement in the growth and vigor of plants through uniform emergence and better establishment of seed. Generally during seed priming, seed has been dipped inside the limited amount of water, inorganic solutions or osmo-protectants for a particular period of time that leads to significant changes in the physiological or metabolic profile of seedlings as well as increase the capacity of seedlings to withstand stress exposure (Tanou et al. 2012; Hussain et al. 2016).

Various reports show beneficial effect of seed priming via uniform or early germination, increased nutrient extraction, reduced seed dormancy, etc (Taylor and Harman 1990; Bruce et al. 2007; Hill et al. 2008; Farooq et al. 2009; 2019). According to the published studies, It has been broadly mentioned that priming of seeds mitigates the adverse impact of various biotic such (phytopathogens, plant diseases; Van Hulten et al. 2006), and abiotic (drought, salinity, flooding) stress factors, that affect the physiology and metabolism of plants via different mechanisms (Kausar and Ashraf 2003; Basra et al. 2005; Guan et al. 2009; Nayaka et al. 2010; Sharma et al. 2014; Kumar et al. 2016). In some cases priming of seeds modulates their biochemical status through improving α-amylase activity even in the low range of temperature (Anaytullah, 2007).

Currently, different priming techniques such as hydro-priming, osmo-priming, solid matrix priming, nutria-priming (Majda et al., 2019), chemo-priming, thermo-priming, and bio-priming (Panuccio et al., 2018) are being used in order to improve seed characteristics, plant productivity as well as alleviate many environmental stresses (Paparella et al., 2015). Each technique has certain limitations and advantages, many reports are also available regarding seed priming that showed beneficial or deleterious effects of priming (Tarquis and Bradford, 1992). The selection of a particular methodology to induce seed germination is determined by the selected plant species, seed attributes, and procedures employed for priming (Ellis and Butcher, 1988; Hill et al., 2008; Ibrahim, 2016; Paparella et al., 2015). The use of microbes for seed priming is a viable and promising approach in the context of improvement in seed characteristics under changing environmental conditions. Seed bio-priming involves the integration of beneficial microbes including bacteria and fungi for improved plant growth and development. In addition, the microbe or plant derived secondary metabolic products like phytohormones and plant extracts (Panuccio et al., 2018) have also been documented for seed priming (Hamayun et al., 2010).

Some of the commonly reported microbes for seed priming are species of *Trichoderma*, *Enterobacter*, *Pseudomonas* and *Bacillus* (Raj et al., 2004). Positive influences of vegetable seed bio-priming based on treatment with strains of *Trichoderma harzianum* over other bacterial and fungal species has been reported by Ilyas (2006).

Endophytes:

It has been established that many of the applied bacterial, fungal, and mycorrhizal species (Balestrini et al., 2018) develop intimate endophytic association with seed of interest for priming and help considerably in overcoming the negative consequences of imposed by various stress factors (Waller et al., 2005). To date, various endophytic bacterial (Joe et al., 2012) and fungal strains have been identified and applied as plant or seed inoculants to enhance the growth and yield of crops. The intimate symbiotic interaction of endophytic bacterial species with host plants offers vast applicability as a potential tool in the agriculture sector in a sustainable manner to improve the crop growth and yield (Prasanna et al., 2012). Most importantly, endophytic bacterial strains equipped with nitrogen fixing capability may be well-suited candidates for agricultural improvement strategies because they may provide plants with additional nitrogen (Reinhold-Hurek and Hurek, 1998). Such diazotrophic bacteria, have also been documented for their growth promotion ability including synthesis of phytohormone, siderophores, solubilization of phosphate, restriction of ethylene biosynthesis and induction of resistance against different plant pathogens (Jha and Kumar, 2009), indicating their suitability for crop growth and yield improvement. Further, the capacity of some root endophytic microbes to alternate between root and soil phases and vector nutrients (nitrogen and soil minerals) to plants from the soil in the rhizophagy cycle (White et al., 2018; see Chapter 1), makes these endophytes good candidates for overall enhancement of the nutritional status of crops. Rhizophagy cycle microbes have also been shown to be important in stimulation of seedling development (Verma et al., 2017); seeds without these endophytes often possess roots that fail to show proper gravitropic response, where roots lay on the surface of soils, and do not form root hairs (Verma et al., 2017). It is evident that plants naturally depend on endophytic microbes for proper development, nutrient acquisition, growth and health (Verma and White, 2019).

Seed priming with endophytic microorganisms due to inherent properties of growth promotion, like phytohormone production, induction of resistance, and tolerance to various abiotic and biotic stresses, could be utilized as an important ecofriendly approach to mitigate the problem of resistance development in plant pathogens as well as for the improvement in crop productivity. However, there are certain limitations of field application of primed seeds in management of crop productivity. The present chapter has been designed with the aim to explore the potential ability of diverse endophytic microbes in seed priming to achieve the goals of sustainable agriculture, methods to overcome limitations associated with field applications along with future perspectives.

Types of seed priming:

There are various types of seed priming techniques are present, some of them are discussed below

Hydro-priming: This technique used for initiating seed germination without emergence of radicle that involves continuous or successive addition of limited amount of water to the seeds under the temperature ranging in between 5 to 20 °C ((McDonald, 1999). The hydro-priming technique is generally used at that agricultural sites where climatic conditions are adverse (McDonald, 2000).

Halo-priming: In this technique, seeds have been immersed in various solutions of salts such as NaCl, KNO_3, $CaCl_2$, $CaSO_4$ etc to start the germination of seed even in the adverse environmental conditions and this treatment enhanced the salinity tolerance as reported in case of wheat by Basra et al. (2005). The priming with potassium nitrate and sodium chloride solutions, causing reduced water potential and increased water absorption by accumulating within the seeds (Parera and Cantliffe, 1994). Similarly working on *Vigna radiata* L. seeds, Jisha and Puthur (2014) transformed the NaCl tolerant variety into more salt and drought tolerant by priming the seeds. Further, their study also showed better and enhanced tolerance capacity of sensitive variety against NaCl and PEG (polyethylene glycol) stress. This simple and economic halo-priming technique has been used acclimate plants under various stresses (Sedghi et al. 2010).

Osmo-priming: In this technique, seeds are dipped in the sugar, polyethylene glycol (PEG), glycerol, $CaCl_2$ solutions for a fixed interval of time (Tabassum et al., 2017) sorbitol, or mannitol followed by air drying before sowing. Normally, after dipping, Water enter inside the seed that may lead to progressive accumulation of ROS (reactive oxygen species) and oxidative damage of cellular components. Osmo-priming checks oxidative injury caused by ROS by delaying the entry of water (Heydecker and Coolbear 1977; Taylor et al. 1998). Osmo-priming appears beneficial for the germination of seed as well as crop performance under both saline and non-saline conditions (Tabassum et al., 2017). In a study Hur (1991) reported treatment of Italian ryegrass (*Lolium multiflorum*) and sorghum (*Sorghum bicolor*) seeds with 20% PEG-8000 for 2 days at 10°C enhanced the rate of germination, under waterlogged, cold-stress, or saline conditions. Thus, osmo-priming may contribute to improved germination rate in part by increasing various enzyme activities.

Solid matrix priming (SMP): It is also known as 'matri-priming' or 'matri-conditioning' technique. This technique has been also used as an alternative of osmo-priming because of less expense, lower volume of osmotic solution and also of temperature and aeration control. In solid matrix priming, seeds have been mixed with solid materials of organic or inorganic origin such as calcium silicate, calcined clay, vermiculite with known water proportion, all these procedures carried out in a sealed container that permits air circulation and avoids excessive evaporation (Harman and Nelson 1994; Rogis et al. 2004; Hacısalihoglu 2007; Ermiş et al. 2016).

Hormonal priming: This is the priming technique in which the seeds have been pretreated with different hormones such as salicylic acid, gibberellic acid, kinetin, which promote the growth and development of the seedlings. There are various reports that show the effectiveness of hormonal priming (Hamada and al-Hakimi, 2001; Hussein et al., 2007 Afzal et al., 2006)

Chemo-priming: In this technique priming of seed is caused by adding conventional disinfectants like sodium hypochlorite, HCl, and also some agrochemicals to prevent microbial contaminations in the priming solutions (Parera and Cantliffe, 1990). Although treatments with NaOCl and HCl solutions reduce losses in germination in comparison to losses caused by pathogens. Furthermore researches have been carried out to critically evaluate the benefit or losses caused by chemo-priming.

Thermo-priming: In this technique seed has been treated at various time intervals before sowing. It is already proved that treatment of seed with altering temperature results in better seed germination as compared to regular constant temperature (Shin et al. 2006; Markovskaya et al., 2007). Altering temperature can break seed dormancy and this technique is popular in improving germination efficiency under adverse climatic conditions (Huang et al. 2002). Alternating temperature of pre-sown treated seed of cucumber and melon, enhances the productivity of plants (Markovskaya et al. 2007). The variation in the ambient temperature influences thermosensory pathway that results in changes in flowering time (Franklin 2009). The nature of the temperature such as hot (Khalil and Rasmussen 1983) and cold (Runkle et al., 1999; Garner and Armitage, 2008) temperature also influence or modulate the time of flowering.

Bio-priming: It is the latest techniques in which seeds have been treated with biological means like beneficial microorganism to protect the seed from diseases or also enhanced the growth and seed germination by modulating various growth hormones (Farooq et al. 2017). The term bio-priming was firstly used by Callan et al. in 1990, during the experiment, in which they coated sweet corn seeds with a bacterial strain. Later on numerous reports have been published that used this techniques to improve seedling growth.

Bio-priming plays an important role in improving germination and viability of seed, growth and yields of plants (Prasad et al. 2016; Bhatt et al. 2015). Like other priming techniques, this helps in improving physiological processes at the pre-sowing phase and also in the multiplication of applied microbes at the area of seed surrounding (Taylor and Harman 1990). It has been found that bio-primed seed is able to provide a better level of protection against various diseases of plants compared to seed treated with various pesticides. The application of endophytic microbes such as bacteria or fungi through bio-priming techniques has potential benefits over traditional priming techniques as because it have sufficient time and environment for the successful colonization inside the seeds.

Factors affecting seed priming processes

The priming of seed may be influenced by various factors such as aeration, quality of seed, temperature, temperature, light, duration (Parera and Cantliffe 1994; Bray 1995).

Aeration is one of the prime factors responsible for the emergence of seedlings and viability of seeds (Heydecker et al. 1975; Bujalski and Nienow 1991). However, the impact of aeration varies with plant species. In a case study of onion, aeration of the PEG solution enhanced the rate of germination in comparison to non-aerated treatments (Heydecker and Coolbear 1977; Bujalski et al. 1989) whereas no impact was found in case of lettuce germination in the aerated and non-aerated K_3PO_4 (Cantliffe 1981).

Temperature is also one of the important factors that influence seed priming. The range of temperatures during priming varies between 15 and 30°C, but in most plant species priming at 15°C improves overall performance of seed (Bradford 1986; Basra et al. 2005). The lower range of temperature generally slows down the rate of germination (McDonald 2000). Similarly, the impact of light on seed priming is also one of the factors that influences rate of dormancy. In a study Khan et al. (1978) reported that illumination at the time of priming of celery seeds may reduce the rate of dormancy, whereas Cantliffe et al. (1981) reported germination of lettuce seed in the dark enhances performance.

Role of endophytes in seed priming

Nature harbors a large diversity of microbial communities, among them endophytes have received increasing attention worldwide because of their promising hidden potential against various biotic and abiotic stress factors, and also their potential applications in growth promotion of plants via modulating growth hormones, nutrient availability, siderophore production, etc. Devoid of their endophytic microbes, seeds of plants do not have the capacity to withstand the stresses caused by various abiotic and biotic factors. The uses of endophytic microorganisms in priming could serve as a viable option to circumvent the limitations associated with seed. Priming has been supposed to induce cellular metabolic processes, hence exposure to any detrimental environmental factors would allow them to respond rapidly and nullify the stresses in an effective manner as compared to non-primed seeds. Further, seed priming with beneficial endophytic bacterial and fungal species may enhance crop productivity significantly.

Application of root endophytic fungi *Piriformospora indica* belonging to class basidiomycetes in order to enhance the disease resistance, tolerance to salinity stress and increase in grain productivity of barley (*Hordeum vulgare* L) is documented (Waller et al., 2005). Endophyte mediated induction of disease resistance was observed to be systemic in nature. The improved defense responses were demonstrated to result from the enhanced antioxidative behavior conferred by ascorbate-glutathione cycle, leading to increase in grain productivity. The fresh shoot weight of four-week-old endophyte infested barley was recorded to be 1.65 fold higher compared to the control group. The grain yield increase for two different barley cultivars i.e. 'Annabell' and 'Ingrid' was found to be 11 and 5.5%, respectively and was attributed mainly to the rise in number of ears per plant. Thus, the increase in shoot fresh weight was directly correlated with the increase in grain yield. Interestingly, the endophyte was also capable of enhancing grain yield in soil systems receiving high nitrogen input. The easy *in vitro* cultivation of the *Piriformospora indica* without the requirement of host cells suggests the effective utilization of fungus for improving the resistance against plant diseases and enhanced grain yield.

Induction of seedling growth in the wheat by inoculation with plant growth promoting endophytic bacterium *Bacillus subtilis* strain 11BM is presented (Egorshina et al., 2012). The inoculation with endophyte was found effective in increasing root and shoot weight as compared to control sets. Wheat seeds treated with endophyte spores culminated into the transient rise of hormonal status of IAA and IBA in the seedlings of root as well as shoot. The considerable alteration in wheat plant hormones was considered as a prime mechanism responsible for induced seedling growth.

There are reports of seed priming with endophytic fungus *Epichloë* (=*Neotyphodium*) on the growth of *Festuca sinensis* under greenhouse environment indicating beneficial impacts (Peng et al., 2013). The interactive investigations were conducted in combination with hydro-priming. Significant improvements were recorded for seedling germination, seed vigor index, above ground biomass, number of leaves, radical and coleoptiles length as well as dry weight of seedlings.

The species endophyte *Epichloë* have been reported to enhance the seed germination of *Festuca arundinacea* (Pinkerton et al. 1990), *Lolium perenne* (Clay 1987) and *Achnatherum inebrians* (Li 2007) under water stressed condition. The probable mechanisms of stress tolerance were attributed to the reduced seed germination time and increase in germination rate conferred by the endophyte. In addition, the endophyte may also modulate antioxidant defense system based on enzymatic activities of superoxide dismutase and peroxidase causing increased tolerance to reactive oxygen species (ROS) produced under stress condition (Zhang and Nan 2007, 2010). Moreover, high seed germination rates could provide competitive benefits to surviving species as compared to those not treated with endophytes (Gundel *et al.* 2006).

Experimental investigations have shown that the tall fescue (*Festuca arundinacea*) endophyte *Epichloë coenophiala* significantly altered the chemistry of the root (Malinowski *et al.* 1998) without direct involvement leading to increased root biomass and could be envisaged as a mechanism for providing tolerance to host system under water stress environment. The fungal endophyte (*Epichloë coenophiala*) association with host (tall fescue) has been demonstrated facilitate the rapid uptake of mineral nutrients and transfer to shoot system leading to improved growth (Malinowski *et al.* 2000). This growth enhancement is likely the result of *Epichloë*-induced stimulation of increased root exudation, with resultant increased nutrient mining by microbes in the rhizophere, followed by increased rhizophagy cycle activity and oxidative nutrient extraction from microbes in root cells (White et al., 2018). It is common in grasses of many species infected by *Epichloë* endophytes, that the fungus colonizes only aerial parts of plants, but stimulates symbiosis with soil microbes in roots, which results in increases in plant size.

Vázquez de Aldana et al. (2013) has assessed the potential of endophyte *Epichloë festucae* on seed germination of two different lines of *Festuca rubra* in arsenic contaminated soil. The study revealed the positive influence of endophyte on radicle length of germinated seeds as compared to those free from endophytes, suggesting that the symbiotic association with the host system could be exploited for crop improvement even under metal contaminated sites. In another experimental investigation, regarding the effect of an endophyte in genus *Epichloë* on water stressed ecotypes of *Festuca sinensis* under controlled green house conditions, the study revealed the beneficial effects of endophytic association (Wang et al., 2017). The positive impact of endophyte association under water stressed environments was represented in terms of increased seedling biomass, plant growth and stem diameter.

Endophytic bacterial species equipped with plant growth promoting traits may induce tolerance to salt stress by modulating the morphological, physiological and biochemical characteristics of plants (Mahmood et al., 2016), suggesting their utilization in crop enhancement under stress conditions. Priming of seeds from two barley genotypes (Haider-93 and Frontier-87) with endophytic bacterial strain *Enterobacter* spp. FD17 was performed to elucidate the role of bio-priming in alleviation of salt stress (Tabassum et al., 2018). Seed priming was helpful in improving grain yield, photosynthetic pigments, soluble protein accumulation, membrane stability and osmolyte concentration. The increased osmolyte concentration under salinity stress may be the outcome of endophyte induced enhanced expression of genes governing the synthesis of osmolyets (Miotto-Vilanova et al., 2016). Moreover, the bacterially synthesized osmolytes may act in synergistic fashion with plant produced osmolytes to enhance the tolerance against the salinity stress (Dimkpa et al., 2009). The order of different priming technique was observed as osmo-priming > bio-priming > hydro-priming. In conclusion, endophytic bacterial association was positively associated with seedlings biochemical and physiological attributes under salinity stress. Effect of inoculation of two different endophytic bacterial strains namely, *Burkholderia phytofirmans* (PsJN) and *Enterobacter* sp. (FD17) in combination with biochar has been performed to alleviate the negative consequences of salinity stress in maize (Akhtar et al., 2015). The bacterial endophyte inoculated maize seeds when applied in combination with biochar were much effective in minimizing the detrimental effects of salinity by reducing the absorption of sodium ions in xylem or by maintaining the nutrient balance of plant system. The better activity (in terms of reducing sodium ion uptake) in biochar added soil was recorded for *Enterobacter* sp. (FD17) as compared to *Burkholderia phytofirmans* (PsJN). The inoculation with endophytes resulted into increase in stomatal conductance (g_s), as well as photosynthetic rate (A_n) for both saline and non-saline soil as compared to un-inoculated soil system. The endophyte mediated enhancement in the selected photosynthetic parameter i.e. g_s as well as A_n however, was much prominent for saline soil amended with biochar. Further, the bacterial strain PsJN was recorded as more potent endophyte in enhancing the photosynthetic parameters g_s and A_n for maize leaves as compared to strain FD17 under saline soil conditions implemented with biochar. In contrast, there were no considerable differences between the two bacterial strains inoculated in non saline soils receiving the same quantity of biochar. Such improvements in plant physiological processes under saline environment could be employed for enhancing the crop productivity in a sustainable manner.

Bu et al. (2019) explained the effects of endophyte *Epichloë sinica* on *Roegneria kamoji* seedlings under artificial drought stress rendered through polyethylene glycol (PEG). The presence of endophyte was observed to enhance the germination potential as well as the rate of seedling emergence for seeds treated with increased concentrations of PEG. On the other hand, the seeds primed with endophyte had significantly lowered content of reactive oxygen species (ROS) in seedling leaves even in the presence of high content of PEG-6000. Moreover, considerable changes in root and shoot morphology was also noticed for seedlings harboring endophytes as compared to those not having endophytic association. The promising outcome with endophytic microbes could serve as a strong base for improving crop productivity under water stress conditions.

The endophytic fungus *Piriformospora indica* induced alternation in plant metabolites under drought stress is recently elucidated (Ghaffari et al., 2019). The barley seedlings primed with endophyte cell suspension under mild drought stress has been presented to have changes in abundance of total 145 plant proteins in contrast to 104 in untreated seedlings. On the other hand, under severe drought stress environment, plant proteins showing considerable changes in their abundance were recorded as 144 and 462, respectively for endophyte treated and untreated ones.

The plant proteins showing changes were related to primary plant metabolic activities and documented to be involved in alleviating the negative effects imposed by oxidative stress under drought. Root colonization by endophytic fungi was associated with enhanced biological functions of photosynthetic machinery and electron transport pathway, in addition to induced build up of proteins with protective role in different biological processes including energy production, primary metabolic pathways and autophagy. Resource redistribution in host cells along with maintenance of water channels (aquaporins) in endophyte inoculated plants as the effective mechanisms to cope up with the detrimental consequences of drought stress could be considered for managing agricultural productivity under changing environmental conditions.

Inoculation effect of endophytic fungi together with the biocontrol agent *Trichoderm viride* in terms of plant growth and content of steroidal lactones (Withanolide A) in *Withania somnifera* (Indian Ginseng) has been emphasized (Kushwaha et al., 2019). The combined treatment with biocontrol agent and endophytic fungi *Aspergillus terreus* strain 2aWF (2aWF), *Penicillium oxalicum* strain 5aWF (5aWF), and *Sarocladium kiliense* strain 10aWF (10aWF) in *W. somnifera* resulted into an increase in shoot weight (65–150%), root weight (35–74.5%) and plant height (15–35%) after 150 days of inoculation as compared to untreated plants. In combined treatment, the Withanolide A content was reported to be increased by 109–242%. Interestingly, the Withanolide A content in root was observed to be raised by 19–73%, in contrast to the no increase in those inoculated with *T. viride* alone. The combined treatment was effective in enhancing the chlorophyll a content upto 115–164% as compared to control ones. Further, the co-inoculation was also reported to influence the expression of genes participating in Withanolide biosynthesis. The up-regulation of resistance gene (NPR1) by 3−7 folds in combined treatment could be exploited for medicinal plants protection against the fungi causing root knot disease.

The role of endophytic fungi *Serendipita indica* and *Atractiella rhizophila* (SML-TX-18) in seedling growth and nutrient acquisition under pot condition has been demonstrated for *Quercus virginiana* (Jin et al., 2019). After 60 days of treatment, the endophyte exhibited growth promotional effects on selected plants. The inoculated seedlings accumulated higher content of total nitrogen in above ground biomass, although the differences as compared to un-inoculated were insignificant. The content of total potassium in treated seedlings was considerably improved under the influence of endophyte inoculation as compared to control ones. The positive influence of seedling treatment with endophytic microbes substantiates the significance of microbiome assisted ecofriendly techniques for improving growth and development of seedlings.

Future perspective

The application of beneficial endophytes to enhance plant performance under natural environmental conditions is of immense importance in the area of agricultural sciences. Since, impacts imparted by endophytic microbes used for seed priming is greatly influenced by host plant as well as prevailing environmental conditions, critical investigations under field conditions should be performed to harness the potential of seed primed with endophytes in crop productivity enhancement. The interactive effects of other priming techniques with endophytic microbe based bio-priming could provide better outcomes for the management of crop productivity. More studies under field conditions for widely distributed endophytic arbuscular mycorrhizal and other endophytic fungi could provide novel and beneficial approachs to combat the problem of reduced crop productivity imposed by abiotic and biotic stresses. The search for newer endophytic bacterial and fungal species would provide many opportunities for different plant species. Moreover, the application of nitrogen fixing endophytic bacteria for seed priming have potential to enhance the seed characteristics in terms of seed vigor, germination rate and overall crop productivity under changing environmental conditions. The identification and transfer of endophytic fungal and bacterial species genes responsible for crop improvement such as disease resistance and stress tolerance genes would be helpful in simultaneous improvement of seed quality and enhancement in agricultural productivity. In this context, the findings that the resistance genes harbored by uncultivable endophytes give a potential avenue for application in plant disease management. Further, the detailed investigations of improved plant disease resistance under the influence of microbial endophytes would help to unveil the precise molecular mechanisms of host protection. .

Conclusion

Application of endophytes for seed priming has several promising potentials in the field of seed technology and agricultural productivity. Available evidence has shown the positive influence of priming on seed quality, seedling growth, crop productivity even under stress conditions. Priming with endophytes has also shown increases in disease resistance, and tolerance to numbers of biotic and abiotic stresses. Few studies regarding the combined application of endophyte based priming with other priming methods like osmo-priming and hydro-priming may have more conspicuous impacts on plant performance under natural environmental conditions as compared to those manifested by bio-priming alone. Extensive research on bio-priming using endophytes could give new insights and a better understating of endophyte and host relationships.

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Table 1: Impact of endophytes on seed priming

Endophyte	Plant	Condition	Response	References
Acremonium loliae	*Lolium perenne* and *Festuca arundinacea*	Greenhouse	Seeds from infected plants of both species exhibited a higher rate of germination	Clay (1987)
Chrysosporium pseudomerdarium, *Aspergillus fumigatus* and *Paecilomyces* sp.	*Glycine max* L.	Lab	Increased rate of germination, germination index, shoot and root length and vigour index	Waqas et al. (2012)
Neotyphodium coenophialum and *Neotyphodium uncinatum*	*Festuca arundinacea Schreb., Festuca pratensis Huds.*	Field	increased plant seed weight, number of seeds per plant and number of panicles	Majidi and Mirlohi (2016)
Neotyphodium	*Festuca sinensis*	Greenhouse	Improve seed germination and plant growth	Peng et al. (2013)
Serratia plymuthica S13	*Cucurbita pepo L.*	Field	Increase germination rates and suppress symptoms of desiccation	Fürnkranz et al. (2012)
Pseudomonas sp. MN12	*Triticum Aestivum*	Field	Improve the productivity and grain biofortification	Rehman et al. (2018)
Pseudomonas sp. IMBG294; *Methylobacterium* sp. IMBG290	*Solanum tuberosum* L.	Lab	Enhance growth of potato shoots and plant became resistance towards the soft rot disease	Pavlo et al. (2011)
Achromobacter xylosoxidans; *Bacillus pumilus*	*Helianthus annuus* L.	Photoperiod chamber	Enhance growth of seedlings under water stress, produce SA, and inhibit	Forchetti et al. (2010)

			growth of pathogenic fungi	
Fusarium oxysporum Fo47	*Solanum lycopersicum* L.	*In vitro*	Reduction of pathogen growth	Aimé et al. (2013)
Achromobacter xylosoxidans, AUM54	*Oryza sativa*	*In vitro*	Increase rice germination and seedling vigor index	Joe et al. (2012)
Phomopsis liquidambari	*Oryza sativa*	Field	Promoted growth of rice	Chen et al. (2013)
Beauveria bassiana and *Purpureocillium lilacinum*	*Gossypium hirsutum*	Greenhouse	Plant growth enhanced	Lopez and Sword (2015)
Neotyphodium coenophialum	*Festuca arundinacea*	Lab	Enhance plant nutrient supply	Van Hecke et al. (2005)
Peronospora indica	*Nicotiana attenuate*	Pot	Enhanced seed germination, plant growth and increased stalk elongation	Barazani et al. (2005)
Gaeumannomyces cylindrosporus	*Zea mays L.*	Greenhouse	Increased heavy metal tolerance; improved height, root length, and fresh weight of treated seedlings	Yihui et al. (2017)

Table 2: Some seed approaches to ameliorate salinity stress across susceptible plant species

Type of priming	**Agents**	**Plants**	**Stress type**	**Mechanism**	**References**
Halo-priming	$CaCl_2$	*Cucumis sativus*	Salinity	Increased proline accumulation	Joshi et al. (2013)
	$CaCl_2$	*Gossypium Hirsutum*	Salinity	Species-specific effect; low germination	Xiao-Fang et al. (2000)
	$CaCl_2$	*Cajanus cajan*	Salinity	Accumulation of proteins, free amino acids and soluble sugars	Verma and Srivastava (1998)
	NaCl	*Nigella sativa*	Salinity	effective in encouraging seed	Gholami et al. (2015)

				germination	
	$CaSO_4$	*Triticum aestivum*	Salinity	concentration of K^+ increased	Afzal et al. (2008)
	KNO_3	*Solanum lycopersicum*	Salinity	catalase activity increased and good amount of protein content and chlorophyll content observed	Vaktabhai and Kumar (2017)
	NaCl	*Oryza sativa* L.	Osmotic	Attributed to increased accumulation of primary metabolites, increased activity of photosystems and mitochondria, and by the activation of antioxidant systems	Jisha and Puthur (2014a)
	NaCl and PEG	*Vigna radiata* L. (Pusa 9531)	Drought	Proline accumulation	Jisha and Puthur (2014)
Osmo-priming	Polyethylene glycol 6000	*Agropyron elongatum*	Drought	Germination percentage and speed of germination decreased	Rouhi et al. (2015)
	Nitric oxide	*Jatropha curcas*	Salinity	Increased accumulation of glutathione and ascorbate in the endosperm-embryo axis; higher activities of catalase 1, catalase 2 and glutathione reductases (GR1 and GR2)	Gadelha et al. (2017)
	Polyethylene glycol	*Medicago sativa* L.	Drought	Enhanced peroxidase and catalase activity, reduced	Mouradi et al. (2016)

				the malonyldialdehyde content and electrolyte leakage under water deficit	
	NaCl	*Medicago sativa* L.	Salinity	enhancement of seed vigour	Yacoubi et al. (2013)
	Polyethylene glycol	*Cuminum syminum* L.	Drought	Accelerate seed germination and improved germination rate	Rahimi (2013)
	Ascorbic acid	*Cucurbita pepo*	Salinity	Catalase and peroxidase activity increased	Fazlali et al. (2013)
	Spermine	*Oryza sativa*	Salinity	Enhancement of Osmo-protection	Paul and Roychoudhury (2016)
Hydro-priming	H_2O	*Triticum aestivum* L.	Moisture	Increase germination percentage and homogeneity of seedling emergence	Meena et al. (2013)
	H_2O	*Brassica rapa subsp. pekinensis*	Salt	accumulation of proline and decreased MDA concentrations	Yan (2016)
	H_2O	*Vigna radiata* L.	Water	increase seedling emergence	Ghassemi-Golezani et al. (2014)
Hormone Priming	Ethylene	*Cajanus Cajan*	Cadmium	Improve germination	Sneideris et al. (2015)
	Gibberellic acid	*Foeniculum vulgare*	Salinity	ABA biosynthesis is suppressed which triggers efficient germination	Sedghi et al. (2010)
	Methyl jasmonate	*Brassica oleracea*	Salinity	contents of indolic glucosinolates, glucobrassicin, neo-glucobrassicin, anthocyanins and	Hassini et al. (2017)

				chlorogenic acid derivatives increased	
	Gibberellic acid	*Cicer arietinum* L.	Drought	Increased seed emergence and plant vigor	Shariatmadari et al. (2017)
Chemo-priming	Mannose, Mannitol and H_2O_2	*Triticum aestivum* L.	Drought	Elevating level of antioxidants, reducing oxidative damage of biomolecules and accumulating more reducing sugars for osmotic adjustments.	Hameed and Iqbal (2014)
Nutri-priming	Selenium, Iron and Boron	*Stevia rebuadiana Bertoni*	Salinity	Increased proline content and antioxidant enzyme activities of CAT and SOD	Shahverdi and Tabatabaei (2017)

Table 3: Effect of different conventional priming treatments on seed germination and crop Performance

Priming method	**Agents**	**Plants**	**Result**	**References**
Halo-priming	Potassium Nitrate	*Allium cepa* L.	Enhanced onion seedling performance and the yield	Duga et al. (2015)
		Solanum lycopersicum L.	Good germination rate index and catalase activity under higher salinity displaying	Vaktabhai and Kumar (2017)
		Helianthus annuus	Improved seed germination, germination rate, seed vigor index, shhot , root, seedling dry weight	Pirmani et al. (2013)
Hydro-priming	Water	*Triticum aestivum* L.	Increase grain yield	Meena et al. (2013)
		Vigna radiata L.	Improved	Shukla et al.

			membrane permeability, high activity of catalase and superoxide dismutase, and more integrated chloroplast and mitochondria in primed seeds	(2018)
		Triticum durum; *Hordeum vulgare*	Speed of emergence of radicle, coleoptile and side roots and the seedling fresh weight were enhanced	Djébali (2012)
Osmo-priming	Potassium Nitrate	*Vigna unguiculata* L.	Greater seed germination and seedling height	Singh et al. (2014)
		Medicago sativa L.	Enhanced the activity of peroxidase, catalase and reduced the malonyldialdehyde content	Mouradi et al. (2016)
		Solanum esculentum L.	Improved germination	Pradhan et al. (2015)
	Chitosan	*Triticum aestivum* L.	Improved germination rate, and shoot and root length	Hameed et al. (2014)
	Polyamines	*Helianthus annuus* L.	enhance the germination and early seedling growth	Farooq et al. (2007)
		Lycopersicon esculentum Mill	improved seed germination, seedling vigour and enhanced anti-oxidative activity	Afzal et al. (2009)
Hormo-priming	Salicylic acid	*Anethum graveolens* L.	Improved the germination rate, germination percentage, radicle	Espanany and Fallah (2016)

			elongation, plumule elongation, and radicle dry weight	
	Gibberellic Acid-3 (GA_3)	*Leymus chinensis*	Increased seed germination rate, promoted plant growth and biomass production	Ma et al. (2018)
Bio-priming	*Trichoderma asperellum*	*Pisum sativum*	Enhancement in plant growth, increase in shoot length, root length, number of leaves, shoot fresh weight, root fresh weight, shoot dry weight and root dry weight	Singh et al. (2016)
	Trichoderma viride 01PP; *Trichoderma harzianum* Th azad	*Cicer arietinum*	Reduced the wilt incidence, and increased seed germination and plant growth parameters	Kumar et al. (2014)
	Pseudomonas fluorescens	*Helianthus annuus*	Shoot height, root length and seedling Weight	Moeinzadeh et al. (2010)