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Biopriming: A prospective techniques for crop improvement

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Abstract

Biopriming has been defined as a process in which biological and physiological treatment of seed is done with the aim of better plant growth by preventing pathogen attack and improved seedling development. This ecofriendly technique has various beneficial effects on seeds in view of agriculture development. Different bacteria and fungi have been used in biopriming technique, in which Pseudomons and Trichoderma species are the most common microorganisms used for this purpose. Current study defines biopriming and reviews the procedures and results of applying these strategies in previous studies. This distinction with introducing new concepts can be useful and helpful to the researchers in the future studies. Furthermore, a brief account of implementation procedures of the seed biopriming has been provided.

Keywords: 1. Fungi 2. Abiotic stress 3. Seed 4. Priming 5. Rhizobacteria 6. Pseudomonas 7. Trichoderma.

Introduction

Providing food security taking into account the limitations of crop productions is one of the main goals of agriculture. In order to deal with this problem, the scientists have attempted to increase the crop yield in agricultural fields using the available sources (Hasanuzzaman, 2019). On the other hand, chemical pesticides have commonly been utilized by farmers throughout the world for increasing the crop production, while they have various hazards for the environment and human health (Damalas and Koutroubas, 2016). Therefore, scientists have suggested the promotion of plant health by improving of plant properties. Speedy and identical seed germination is vital for suitable crop establishment to assure economic constancy in commercial agriculture and proficient usage of production resources (Chen and Arora, 2013). The procedure of seed germination might be controlled by outer factors that involve environmental conditions such as temperature, light, soil moisture, and salinity, metal, or mineral composition (Ghaderi-Far et al.,2010; Jain et al.,2009).

One of the efficient and low-cost approach for the improvement of various features of plants is seed priming, which is defined as application of compounds with natural or synthetic origins that stimulate or induce especial state of seedling physiology after germination periods (Parera and Cantliffe, 1994) or using water or specific solutions with low osmotic potential for seeds in order to control hydration (Farooq et al., 2010). Different types of priming include: hydropriming,halopriming,osmopriming, chemical priming (chemopriming), thermopriming, hormonal priming, biopriming, organic priming, redox priming, nutripriming, solid matrix priming, and nanopriming (Neamatollahi and Souhani-Darban, 2010; Sun et al.,2011; Hasanuzzaman, 2019; Acharya et al., 2020) (Table 1).

Table 1. Types of priming and their definitions.

Type of priming	Definition	Reference
Biopriming	Treatment of seeds with fungi or bacteria (Beneficial microbes)	Waller et al., 2005
Hydropriming	Soaking of seeds in water followed by drying without radicle appearance	Fortiet al., 2020
Halopriming	Pre-sowing soaking of seeds in salt solutions	Afzal et al., 2008;Luttset al., 2016
Hormopriming	Treatment of seeds with plant growth regulators	Luttset al., 2016; Ma et al., 2018

Osmopriming	Soaking the seeds in aerated osmotic solutions with considering diverse water potentials and time periods	Mirmazloumet al., 2020
Chemical priming	Treatment of seeds with economic and safe chemicals	Hameed and Iqbal, 2014
Thermopriming	Treatment of seeds with low or high temperatures	Tzortzakis, 2009
Nutrient priming	Treatment of seeds in mineral nutrient solutions	Muhammad et al., 2015
Solid matrix priming	Treatment of seeds with a solid material (with chemical and physical characteristics) to limit the water imbibe in seeds	Mercado and Fernandez, 2002
Nanopriming	Treatment of seeds with nanoparticles (NPs)	Acharya et al., 2020

The seed treatments give some beneficial features to seedlings so that they can protect themselves against pests and diseases. Also, the treated seeds could improve root development, seedling emergence, inducing the structural and ultrastructural modifications for water imbibe, decreasing the stress at the germination stage, establishment rates, and enhancing in the activity of enzymes which convert macromolecules to materials needed and applied for the embryo's growth and development (Bewley and Black, 2012; Galhautet al.,2014). These advantages will give some benefits to the farmers in saving time, cost, and other works such as fertilization, weed management, etc.(Acharya et al., 2020).

One of the well-established technologies in agriculture is the use of beneficial microorganisms for improving the plant growth. These microbes might apply in various aspects of agriculture as biofertilizers, biostimulants, or biocontrol of phytopathogens (Swaminathanet al., 2016). Also, they can play main roles in seed biopriming. Seed biopriming has been referred as a process of utilizing fungi or bacteria on seeds. Beneficial microorganisms with endophytic activity can contribute by improving the host development and resistance against biotic and abiotic conditions. (Waller et al.,2005). The substitution of chemical pesticides with beneficial microorganisms can play an essential role in protecting the soil, plant, and environment owing to their eco-friendly features (Prasad et al., 2016). Various genus of bacterial and fungi such as Azotobacter, Azosprilium, Pseudomonas, Bacillus, Serratia, Burkholderia, Agrobacterium, Rhizobium, Lactobacillus, Pediococcus, Trichoderma, Gliocladium, Pythium, Clonostachys, Fusarium, and Metarhizium have been used for seed biopriming in many studies (Table 2).

Table 2. Using the different bacteria and fungi in seed biopriming with their effects on hosts.

Mycopriming	Bactopriming	Pathogen/Stress	Host	Effect	Reference
_	Pseudomonas fluorescens	Pythium ultimum(damping-off)	Corn (Zea mays)	Damping-off tolerance	Callan et al., 1991
Trichoderma harzianum	_	Pythium spp .	Cucumber (Cucumiss ativus L.)	Providing a physical barrier that delayed the pathogen attack and resulted in a conducive environment for T. harzianum growth	Taylor et al., 1991
GliocladiumvirensandTrichodermaviride	Burkholderiacepacia	Pythium ultimumP. arrhenomanes and Fusarium graminearum	Corn (Zea mays)	Reducing the diseases severity	Mao et al., 1997
_	Pseudomonas fluorescens	Sclerospora graminicola(Downy mildew)	Pearl millet (Pennisetumglaucum)	Plant growth enhancement and resistance induction against downy mildew	Raj et al., 2004
Clonostachys rosea	_	Alternariadauci and A.	Carrot	Reduction the incidence of	Jensenet al., 2004

		radicina		pathogens and improvement the health of seedling -	
_	Serratiaplymut hica	Verticillium dahliae	Oilseed rape	Significant biocontrol of the pathogen	Müller and Berg, 2008
Trichoderma virideT. harzianum and T. hamatum	Bacillus subtilisB. cereus and Pseudomonas fluorescens	Rhizoctonia solaniFusari umsolani and Atheliarolfsi i(Root rot)	Faba bean (Viciafaba e)	Reduction in disease incidence	El-Mougy and Abdel-Kader, 2008
_	Agrobacterium rubiBurkholderi agladiiPseudom onasputidaB. subtilis and Bacillus megaterium	Salinity stress	Radish (Raphanus sativus L.)	Improvement the seed germination	Kaymaket al., 2009
Trichoderma harzianum	_	Fusarium verticillioide s	Maize	Reduction in the pathogen infection and increasing in the yield seed germination vigor index field emergence and 1000 seed weight	Chandra et al.,2010
Trichoderma harzianum and T. virens	_	Pythium aphaniderm atum	Cucumber (Cucumiss ativus L.)	Increasing in seedling emergence and shoot fresh weight and decreasing in damping-off	Pill et al., 2009

				disease	
Clonostachys rosea Trichoderma harzianum and T. viride	Pseudomonas chlororaphis an d P. fluorescens	_	Carrot and onion	Increasing in the seed emergence and yield	Bennett et al., 2009
_	Pseudomonas aeruginosa and Burkholderiace pacia	Atheliarolfsi i	Chilli (Capsicum annum L.)	Reduction in the pre- and post-emergence damping-off caused by pathogen using increasing the activity of peroxidase polyphenol oxidase and phenylalanine ammonia lyase	Siddiqui and Meon, 2009
Trichoderma harzianum a nd T. virens	Pseudomonas aeruginosa	Colletotrich umtruncatu m	Soybean	Controlling of the damping-off caused pathogen and improvement the percentages of seed germination	Begum et al., 2010
_	Pseudomonas fluorescens	_	Sunflower (Helianthu s annuusL.)	Enhancement of seed indices and improvement of seedling growth	Moeinzad ehet al., 2010
_	Azotobacter spp. and Azosprilium spp.	_	Corn (Zea mays L.)	Increasing in the grain yield and dry matter accumulation	Sharifi, 2012

_	Azotobacterspp. and Azospirillum spp.	_	Corn (Zea mays L.)	Increasing in the grain yield plant lengthnumber of kernels and number of grains	Sharifi and Khavazi, 2011
_	Pseudomonas sp.	_	Alyssum serpyllifoliumAlyssum serpyllifoliumand Brassica juncea	Increasing in the biomass	Ma et al., 2011
_	Paenibacilluslentimorbus	Drought stress	Chickpea(Cicer arietinum)	Increase in the germination percent of chickpea	Khan et al., 2011
_	Azotobacterchroococcum Azospirillumlipoferum	_	Maize (Zea mays L.)	Increasing in grain yield drymatter accumulation and crop growth rate	Sharifi, 2011
_	Bacillus cereus	Salinity stress	Mungbean (Vigna radiate)chickpea(Cicer arietinum) andrice(Oryza sativa)	Increasing in the seedling height number and length of leaves root and shoot biomass eliciting the antioxidant responses against salt stress in the plants increasing the activities of	Chakraborty et al.,2011

				superoxide dismutase peroxidase ascorbate peroxidase and catalase inducing the activities of chitinase 1- 3 glucanse and phenyl alanine ammonia lyase	
Trichoderma harzianum	_	Pyrenophor atriticir-epentis	Wheat (Triticuma estivum)	Reducing in the tan spot severity and enhancing in the plant height and weight	Perelló and Dal Bello, 2011
Trichoderma harzianum	_	Salinity stress	Rice (Oryza sativa L.)	Decreasing in the stress condition increasing in the length and fresh weight of shoot and root number of leaves leaf area photosynthetic rate chlorophyll fluorescence and chlorophyll content.	Rawatet al., 2012
_	Bacillus pumilusandB. furmus	Salinity drought and heavy-metal stresses	Potato (Solanum tuberosum)	Enhancement the mRNA expression levels scavenging enzymes and proline content in tubers and increasing the d	Gururanie t al., 2013

				plant tolerance to abiotic stresses	
_	Azotobacterchroococcumand A. lipoferum	_	Barley (Hordeum vulgare L.)	Increasing in 1000-grain weight dry matter production and grain yield	Mirshekariet al., 2012
_	Pseudomonas spp.	_	Safflower (Carthamustinctorius L.)	Increasing in the number of branches heads diameter of head grain number of head 1000-grain weight oil content and grain yield	Sharifi, 2012
_	Azotobacter and Azosprilium	_	Barley cultivars	Increasing in the grain yield	Shirinzadehet al., 2013
_	Azospirillum and phosphobacteria	_	Hybrid maize COH(M)5	Improving the germination root and shoot length dry matter and total dry matter production and vigor index	Karthika and Vananga mudi, 2013
_	Pseudomonas fluorescensTrichodermaasperellum and Rhizobium sp.	_	Chickpea (Cicer arietinum L.) and rajma (Phaseolus vulgaris)	Improving of seed germination and seedling growth	Yadav et al., 2013

Trichoderma viride	Pseudomonas fluorescens	_	Chilli (Capsicum annuum L.)	Increasing in the seed germination and seedling vigor	Ananthiet al., 2014
Trichoderma harzianum	PseudomonasfluorescensBacillusmegaterium and Rhizobium sp.	Fusarium sp.	French bean and Cluster bean	Inducing in the peroxidase phenyl alanine ammonialyase polyphenol oxidase β-1 3-glucanase and chitinase	Kanchana shri, 2015
_	Lactobacillus sakei Pediococcusacidilactici and Pediococcuspentosaceus	Fusarium spp. Bipolarissorokianaand Alternaria spp.	Wheat	Significantly reduction in the incidence of pathogens	Supronieneet al., 2015
Glomus intraradices Glomus mossaeand Trichoderma atroviride	_	_	Wheat (Triticum durum)	Improving the seedling growth yield and grain quality	Collaet al., 2015
Trichoderma spp.	Bacillus subtilis	_	Bean	Promoting the seedling growth	Jungeset al., 2016
Trichoderma harzianum	Pseudomonasfluorescens	Rhizoctonia solani(Sheath blight)	Rice (Oryza sativa)	Controlling the disease and increasing in the plant growth with decreasing in the utilization of chemical	Singh et al., 2016

				pesticides	
Trichoderma asperellum	_	_	Tomato (Lycopersi cumescule ntum) brinjal (Solanum melongena) chilli (Capsicum annuum) okra (Abelmosc husescule ntus) ridge gourd (Luffa) and guar (Cyamopsi stetragono loba)	Enhancing in the seed germination and radicle length increasing in the shoot and root length shoot and root fresh and dry weights and number of leaves	Singh et al., 2016
_	Pseudomonas sp. and Burkholderiasp.	_	Echinacea purpureaa ndLonicer a japonica	Increasing in the root and shoot length fresh and dry weight number of lateral roots	Gupta et al., 2016
_	Bacillus endophyticus B. tequilensis Planococcusrifi etoensis Variovoraxpara doxus and Arthrobacteragi	_	Glasswort(Salicornia europaea)	Increasing in the germination and seedling growth	Zhao et al., 2016

	lis				
_	Bacillus sp. B. cereus and B. subtilis	Salinity stress	Wheat (Triticuma estivum)	Increasing in the growth yield and physiological parameters of wheat.	Shahzadet al.,2017
_	Bacillus subtilis	Fusarium solaniand salinity stress	Chickpea (Cicer arietinum L.)	Reduction the infection rate of root rot disease increasing the plant growth promotion capabilities improvement the symbiotic performance of host with rhizobia and promoting the yield	Egamberdieva et al.,2017
_	Bacillus cereus	_	Felty germander (Teucrium polium)	Increasing in the root length	Hassan, 2017
Uncultured Cladosporium and Metarhizium and Penicilliumbrevicompactum	_	_	Barley	Significant increases in the mean barley seedling length	Murphy et al.,2017

Trichoderma harzianum and T. viride	Bacillus subtilus and Pseudomonas flouresences	Fusarium solaniRhizoctoniasolaniAtheliarolfsii and Macrophominaphaseolina	Soybean (Glycine max L.)	Significantly reduction in the root rot diseases and improvement in both vegetative growth and yield parameters	Monaet al.,2017
Trichoderma harzianum	Pseudomonas fluorescence	_	Common bean (Phaseolus vulgaris)	Enhancement in the germination shoot length root length seedling dry weight seedling vigor index and speed of germination	Monalisaet al.,2017
Rhizophagus intraradices and Funneliformismosseae and Trichoderma atroviride	_	_	Artichoke (Cynarascolymus)	Improving in the plant yield and nutritional value (e.g. antioxidant activity total phenolicscaffeoyl quinic acids and flavonoids)	Rouphael et al.,2017
Trichoderma lixii	_	_	Maize (Zea mays L.)	Increasing the length fresh and dry weight of root/shoot and decreasing in the lipid peroxidation	Pehlivanet al.,2017
_	Bacillus subtilis and Pseudomonas	Xanthomonasoryzae pv. oryzae	Rice (Oryza sativa	Increasing in the seed vigor and decreasing in the	Palupiet al.,2017

	diminuta	(Xoo)	L.)	pathogen infection	
-	Bacillus gaemokensis	Pseudomon as syringae pv. lachrymans	Cucumber (Cucumiss ativus) an d pepper (Capsicum annuum)	Eliciting the immunity disease controlling both in seedlings and in whole plants and increasing in the yield	Song et al.,2017
_	Bacillus sp.Staphylococc ussp. and Arthrobactersp.	_	Ammoden dronbifoli um	Increasing in the seed germination and radicle elongation	Zhu and She, 2018
Rhizophagus irregularis	Pseudomonas putida	_	Cowpea (Vignaung uiculata L.)	Enhancing in the total biomass production seed weight and seed yield significantly increasing in the concentration of nitrogen and phosphorus in shoot and enhancing in both chlorophyll b and carotenoids contents	Rocha et al.,2019
Rhizophagus irregularis	Pseudomonas libanensis	_	Cowpea (Vignaung uiculata L.)	Enhancing in the plant biomass and seed yield	Ma, 2019
Rhizophagus irregularis	Pseudomonas fluorescens	_	Maize (Zea mays L.)	Shoot nutrient concentration increments for	Rocha et al.,2019

				nitrogen phosphorus potassium zinc magnesium and manganese	
_	Azospirillum brasilense	_	Aged seeds of tall fescue (Festucaar undinacea) orchardgr ass (Dactylisgl omerata L.) and Russian wild rye (Psathyros tachysjunc ea)	Significant effect on seedling growth root elongation and the activity of superoxide dismutase	Liu et al.,2019
_	Bacillus subtilisB. altitudinis and B. kochii	Bipolarispan ici-miliaceiCurv ulariasoliNig rosporacam elliae-sinensisFusa riumchlamy dosporum and Curvulariap seudobrach yspora	Rice (Oryza sativa)	Decreasing in the disease incidence of pathogens	Rangjaroe net al.,2019
Trichoderma erinaceum	_	Fusarium oxysporum f	Tomato (Solanum	Increasing in activity of	Aamiret al.,2019

		.sp. lycopersici	lycopersicum L.)	antioxidative enzymes such as superoxide dismutase and catalase and lignified stem tissues	
_	Bacillus spp.	_	Barrel medic (Medicago truncatula)	Significant improve the seed germination and seedling establishment	Fortiet al.,2020
_	Pseudomonas aeruginosa	Rhizoctonia solani	Maize (Zea mays L.)	Significant increasing in the plant growth and antioxidant content and decreasing in the disease severity	Singh et al.,2020

Some beneficial effects of seed biopriming on various features of plant include: seed germination, seedling emergence, seedling vigor (seedling shoot length, root length, wet weight, and dry weight), seedling establishment, seedling field emergence, dry matter production, pathogen control, harvest index, yield parameters, thousand seed weight, systemic acquired resistance (SAR) stimulation, induced systemic resistance (ISR) stimulation, tolerance to salinity, storage at low temperature, storage under anaerobic condition, nutrient solubilization, and nutrient absorption and translocation from soil into seed (Yadav et al., 2013; Karthika and Vanangamudi, 2013; Rehmanet al.,2018a; Rehmanet al.,2018b). Interactions between seeds and microorganisms are complicate. Although the seed coat may be complex, nevertheless the present condition must be balanced for retaining seed dormancy and microbe viability (O'Callaghan, 2016). Different factors such as formulation nature, temperature and relative humidity intervene in the viability of microbes and seeds, but there are limited perfect studies with details about interactions of these factors (Swaminathanet al.,2016).

The purpose of this study was to introduce two new concepts related to seed biopriming technology as well as introducing some studies in which the biopriming has been used in promotion of plant growth and inhibition of pathogens.

Reaction to biotic stresses

The plants likely affected by different biotic and abiotic stress conditions (key constraints for global food and yield) and thus need to protect themselves against these changes (Khushruet al.,2020). Therefore, the degree of phenotypic plasticity determined by the genome can play an essential role in plant survival under stressful conditions (Aamiret al., 2017). The plants defend themselves from pathogens by various methods such as the production of reactive oxygen species (ROS), accumulation of H_2O_2, suberization and lignification of cell walls at the infected sites, and expression of pathogenesis-related (PR) protein genes (Pusztahelyiet al.,2015).

Biopriming has been used as a protection strategy against seed-borne and soil-borne pathogens (Reddy, 2012). Seed biopriming in cucumber, maize, pea, and soybean resulted in controlling of damping-off (Mahmood et al., 2016). Vegetable seeds primed by Trichoderma harzianum, T. pseudokoningii, Bacillus sp., Gliocladium sp., and Pseudomonas fluorescens inhibited the infection of Colletotrichumcapsici (Ilyas, 2006). Some strains of fluorescent Pseudomonas spp., with producing siderophores as ferric ion specific chelating agents, can effectively compete for iron with other microorganisms as well as pathogens. These strains when applied as seed bactopriming, could function as plant growth-promoting and biocontrol agents (Bisenet al.,2015). Maize seed bactopriming by using Bacillus amyloliquefaciens and Microbacteriumoleovorans showed that these biocontrol agents could reduce the population of the Fusarium verticilliodes (Pereira et al., 2007; Pereira et al.,2011). Widely used Trichoderma spp. in agriculture is able to control various phytopathogens such as ascomycetes, basidiomycetes, oomycetes, and nematodes. When these microbial bio-pesticides were used as mycopriming, they could induce the plant systemic resistance and root proliferation (O'Callaghan, 2016). In mungbean, the seed treated with Trichoderma spp. resulted in controlling of Rhizoctoniasolani (Dubey et al., 2001). Plant defense responses in the form of lignification and activity of antioxidative enzymes have resulted in inoculating of tomato seeds using Trichoderma erinaceum against Fusarium oxysporumf.sp. lycopersici(Aamiret al., 2019). Cowpea seed mycopriming using Trichoderma harzianum interestingly resulted in reduction of root rot diseases caused by Macrophominaphaseolina, Fusarium solani, and Rhizoctoniasolani (El-Mohamedyet al.,2006). Pea seed biopriming with co-inoculation of Trichoderma harzianum, Pseudomonasfluorescens, and Bacillus subtilis resulted in the population reduction of Fusarium solani and Rhizoctoniasolani, the causal agents of root rot diseases (El-Mohamedy and Abd-El-Baky, 2008).

Reaction to abiotic stresses

Abiotic stresses adversely affect the plants and limit the plant growth and productivity throughout the world. The common abiotic stresses are drought, salinity, heat and cold temperatures, heavy metal toxicity, and nutrient limitations (Ma, 2019; Rani et al., 2008). Novel strategies in agriculture with reducing the pre/post-harvest losses caused by abiotic stresses can assist with crop yield boosting (Jishaet al., 2013).

In drought stress, the beneficial microorganisms are able to induce the plants for adaptation to this condition using different mechanisms including production of phytohormones and induction the synthesis of defense-related antioxidants and exopolysaccharides (EPS) (Kaushal and Wani, 2016). Seed bactopriming using Bacillus sp. RM-2 strain with ability of phosphate solubilization, ACC deaminase activity, antifungal activity and ammonia and indole acetic acid production significantly influenced the growth and nutrient uptake of the cowpea and increased the seed germination, shoot and root length, fresh weight and dry weight, leaf area, number of pods and seeds and grain yield in natural semi-arid conditions (Minaxiet al., 2012). Seed biopriming of pumpkin plants by Serratiaplymuthica S13 and Lysobactergummosus L101 strains led to strongly germination of pumpkin seeds, increasing emergence rate, enhancing stress tolerance, and reproducible increases in harvest yields under drought stress (Furnkranzet al., 2012). The EPS producing strain Pseudomonas putida GAP-P45 formed a biofilm on the root surface of sunflower seedlings and increased the plant tolerance against drought stress. The coated seedlings with improved soil aggregation, increased relative water content in the leaves under drought stress (Sandhya et al., 2009).

A commercial biofertilizer majorly composed of genus Pseudomonas, Azotobacter, Azospirillium, Agrobacterim, Agrobacterium, Rhizobium, and Bradyrhizobium was used as a cotton seed biopriming. Results showed that seeds coated with biofertilizer improved growth and physiological characteristics of cotton under saline condition (Amjadet al.,2015). Using the drought tolerant Trichoderma harzianum strains as seed biopriming on wheat under drought stress resulted in reducing the stress levels in wheat with decreasing the accumulation of toxic reactive oxygen species (ROS) (Shukla et al., 2015). Trichoderma harzianum strain T22 enhanced seed germination and seedling vigor of tomato under osmotic, salinity, chilling, and heat stress conditions (Mastouriet al., 2010). The beneficial effects of bactopriming and mycopriming, and un-primed states on seeds briefly shown and described in figure 1.

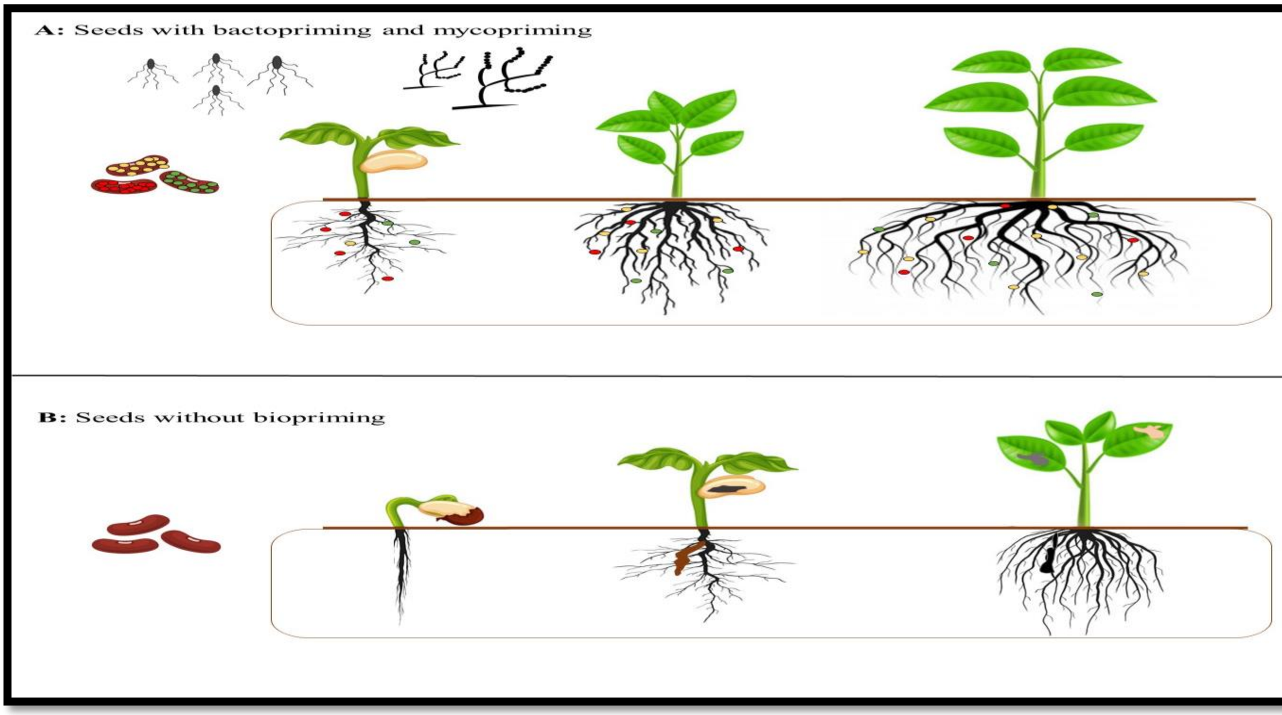

Figure 1.**A:**Mycoprimed and bactoprimed seeds indicated advantages and superiority over un-bioprimed seeds in features of plants, such as growth, germination, seedling establishment, seedling vigor, root length and development,SAR and ISR stimulation, tolerance to extreme factors. **B:** Seeds without biopriming displayed low growth, low development and susceptibility to biotic and abiotic stresses.

Examples of mycopriming and bactopriming methods

Various methods have been used to investigate the seed mycopriming and bactopriming in different studies such as:

-For making spore suspensions, the 100% (w/v) stock suspension of Trichoderma viride Tv1 strain were prepared by mixing the 1.0 g of Tv1 containing 28 × 10^6 colony forming units (CFU) in 1.0 ml of water. The chilli seeds were bioprimed with T. viride at 40, 60, and 80% (w/v) diluted inocula for 3, 6, 9, or 12 h. Biopriming with Tv1 could improve rate of seed germination, the germination percentage, mean root and shoot length, biomass production, and seedling vigor index (Ananthiet al., 2014).

-The conidia of antagonistic Trichoderma hamatum, T. harzianum, and T. viride strains grown on potato dextrose agar (PDA) medium were collected and mixed with sterilized distilled water. Adhesive polymers such as carboxymethyl cellulose (CMC) and pectin were used as adhesive polymers for seed biopriming process. 1.0 L of each of the individual bioagent suspensions with a spore concentration of 10^6 – 10^7/mL was used for biopriming. The seeds of faba bean were imbibed in each of the prepared priming solutions for 16 h.

Under the greenhouse conditions, all the tested bio-primed faba bean seeds showed a significant effect in reduction of root rot disease incidence caused by Rhizoctonia solani, Fusarium solani, and Atheliarolfsii at both pre-emergence and post-emergence stages of plant growth compared with the control treatment (El-Mougy and Abdel-Kader, 2008).

-The conidial populations (1×10^7 conidia/mL) of Trichoderma lixii ID11D (TXD) strain were mixed with 2% CMC and then 1% Tween 20 was added to the solution. 25 mL of suspension in the concentration of 1×10^7 conidia/mL was added to the maize seeds and incubated for 1 h. Seed biopriming agent was investigated under NaCl stress in greenhouse condition. The TXD seed biopriming increased the length, fresh and dry weights of root/shoots of maze and remarkably decreased the lipid peroxidation (MDA) (Pehlivanet al., 2017).

-Trichoderma viride with 2×10^6cfu/mL spores and Frateuria aurentia with 10^8 CFU/mL cells were separately centrifuged and the pellet was suspended in 1.5% CMC. After seed sterilization with hypochlorite sodium 1.5% for 5 min, they were washed three times with distilled water and then primed with microorganism suspensions. In this study, significantly increasing in leaf area, higher chlorophyll content, higher root length, and higher total biomass lead to increased crops yield (Yadav et al., 2018).

-Trichoderma harzianum was grown on Echinochloafrumentacea grains, dried in open air and converted to powder. The powders passed of sieves for obtaining a monotonous powder. For biopriming, the seeds of wheat (Triticumaestivum L.) were sterilized with 1% sodium hypochlorite for 3 min, washed with distilled water and then air-dried. The wheat seeds were mycoprimed with drought powder of T. harzianum with concentration of 5×10^6 CFU/g and then soaked in distilled water and held for 24 h in $25\pm2^{\circ C}$ and moist condition until prior to radical emergence (Shukla et al., 2015).

-Strains of Bacillus spp. with excellent antifungal activity against dirty panicle disease (DPD) caused by fungal genera such as Bipolaris, Curvularia, Nigrospora, and Fusarium were used for rice seed biopriming. The bacteria was cultured on LB medium and then centrifuged for gaining biomass. The biomass was washed twice so that the populations reach to 10^8 CFU/mL. Unhealthy rice seeds were soaked in bacterial suspensions and then dried in air. The optimal biopriming duration for 9 or 12 h supported the lowest disease incidence and longer roots and shoots of rice seedlings germinated (Rangjaroenet al., 2019).

-The arbuscular mycorrhizal Rhizophagusirregularis BEG140 strain was used for maize seed biopriming. For the seed coating, the R. irregularis inoculum after sieving through a 500 µm mesh was mixed with silicon dioxide as coating material. The nitrogen, phosphorus, potassium, zinc, magnesium, and manganese content on maize were positively affected by seed priming with R. irregularis(Rocha et al., 2019).

Future perspectives

The world's utmost need of high crop production to meet population food demand has led to excessive use of chemical fertilizers. Chemical fertilizers pose harmful effects on human health in addition to decreased soil fertility. In view of it, agriculturists need to look an alternative of chemical fertilizers. For that reason, seed biopriming can be a promising alternative for agricultural fertilizers & pesticides. Regarding to the various beneficial effects of seed biopriming, more investigations need to be carried out for finding the new microorganisms suitable for biopriming. Also, easy to use and inexpensive and viable technologies must be developed to encourage the farmers in applying seed biopriming.

Confilict of interest

The authors declare that they have no conflict of interest.

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