

Seed Priming: A Critical Review

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Abstract— India being an agricultural country, more than 80% population of rural India depends on agriculture and its associated activities for their living. To satisfy the requirements of Indian population, there is need for adequate crop yield. But due to urbanisation, pollution, biotic and abiotic stresses, unavailability of micronutrients etc. there are various constraints on seed germination and crop yield. The present review highlights the problems associated with germination and growth of plants. It discusses on seed priming technology that can synchronise seed germination and improve vigour, leading to better crop establishment and yield. Seed priming stimulates the processes involved in metabolism which prevents seed deterioration, breaks dormancy and induces systemic resistance against biotic and abiotic stresses. It explains physiological and biochemical changes occurring in seeds on priming. Extensive study using different seed priming techniques *viz.* hydro-priming, halo-priming, osmo-priming, matrix priming, osmohardening, on-farm priming, hormone priming, nutripriming, biopriming nanoparticle priming etc. has been carried out. Studying the use of different techniques and their need put an insight in the new research area of bionanoseed priming produced by amalgamating nanofertilisers and plant growth promoting rhizobacterias, to improve the productivity of crops.

Keywords—Seed priming, Priming techniques, Germination, Crop establishment

I. INTRODUCTION

Environmental pollution and abiotic stresses are major global problems affecting seed germination, emergence and vigour of seedling and ultimately crop yield [1]. These unfavourable conditions have a severe impact in many agricultural areas especially arid and semi-arid lands [2]. Abiotic stresses affect the plant growth and crop yield by delaying the start of germination and reducing its rate of growth [3]. It also affects soil biota resulting in economic losses. Another constraint in crop yield is the less availability of nutrients in the soil [4]. India being an agricultural country urges the need of simple, effective and manageable technology to enhance establishment of crops under all environmental conditions. Different techniques can be used to enhance crop yield of which, seed priming is the simple and suitable technique to synchronise seed germination, increase emergence and establishment in the farm [5, 6]. Seed priming technique can aid the farmers to reduce the excess use of fertilisers, enhance crop yield by synchronised seed germination, and induce systemic resistance in plants.

This review is organised as follows, Section I includes introduction which describes the need of seed priming, Section II explains seed priming, its mechanism and changes

occurring in seeds, Section III describes various techniques of priming with examples, Section IV lists the beneficial effects of priming, Section V gives an insight where research can be extended and Section VI concludes the work with future prospects.

II. SEED PRIMING

Seed priming treatment is done before sowing seeds, which involves hydration of seeds plentiful enough to enable metabolic events before germination to take place, although preventing radicle emergence to occur [7,8]. Priming is an approach that involves treating seeds with different organic or inorganic chemicals and or with high or low temperatures [2]. It entails imbibition of seeds in different solutions for a specified duration under controlled conditions, then drying back them to their original moisture content, so that radicle do not emerges before sowing. This stimulates various metabolic processes that improve germination and emergence of several seed species, particularly seeds of vegetables, small seeded grasses and ornamental species [9] whereas also reverses the detrimental effects of seed deterioration [5]. Seed priming is considered to be an easy, highly effective, low cost and low risk technique. Primed seeds are more useful because of numerous advantages such as uniformity, early and faster appearance [10], germination

in broad range of temperature, crop establishment, efficient use of water, enhancing roots to grow deeper, allowing germination in dormant seeds by increasing metabolic events, to initiate growth of organs for reproduction [11], early flowering and maturity [12], better competition with weeds, combat against abiotic stresses [3, 13] and soil-borne destructive diseases (*R. solani*, *Fusarium spp.*, *Sclerotium rolfsii* etc.)[14].

Mechanism of priming

Seed germination is a complicated process involving different metabolic events which result in change from stored food reserve to activation phase where radicle and plumule emerges [2]. In general, the seeds intake water by undergoing three phases. First phase is called as Imbibition phase, which involves quick water uptake through forces driven by seeds. In this phase, there are changes occurring such as metabolic activities and translation process takes place whereas DNA and mitochondria are repaired [15]. Second phase is the lag phase where there is less water uptake resulting in minor increase in fresh weight of seeds. This phase is also called as Activation phase as this period is highly active physiologically and metabolically. It helps in maturation of mitochondria (causing ATP synthesis), protein synthesis from new mRNAs and mobilizing stored macromolecules into molecules required for radicle outgrowth [6]. The third phase is germination phase. In this phase, germination is completed and seedling growth starts by recommencement of radicle and quick water uptake. In priming, first and second phase occurs, not allowing seeds to enter phase III [16]. Phase II initially occurs for longer time for performing processes and prevents phase III. So, in primed seeds lag phase is reduced as preparation for phase III is not required, which is already done. Due to this, different benefits are imposed in seeds such as synchronisation of radicle emergence, increase in growth rate and enhancing large number of seeds to germinate. During priming, seeds already complete first two phases of germination, so on sowing; these seeds have the ability to complete the process faster (imbibition) once it is provided with water. This reduces the time required for cellular activities to take place. DNA content increases due to activation and/or synthesis of enzymes of nucleic acid, ultimately increasing total RNA amount and proteins. It also heals the damage caused to cell membrane during storage/drying [17].

Physiological and biochemical changes in seeds on priming

Priming leads to different biochemical and physiological changes in seeds. It synchronizes germination after breaking dormancy [7], diminishes the lag time required for imbibition, hydrolyses or metabolises inhibitors, activates enzymes, mobilises reserved food and enhances embryonic tissue outgrowth [14]. Starch metabolism is of great importance during seed metabolism which influences

seedling vigour under stress. This metabolism is brought about by α -amylases which hydrolyse the starch reserves into metabolisable sugars providing energy to the developing embryo. Seed priming enhances α -amylase and dehydrogenase activity that could hydrolyse the starch macromolecules into smaller and simple sugars with increased ATP production and respiration. Phytase, amylase, and protease also increase during this process. Likewise [2] have shown increased activity of α -amylase in primed barley seeds by 2.8 times, whereas in primed wheat seeds activity was increased by 2.7 times compared to unprimed seeds. This might have led to enhanced germination events in primed seeds.

Priming also helps in improving function of malate synthase and isocitrate lyase which converts lipids into carbohydrates whereas antioxidant enzymes (POD, SOD, CAT and GR) that scavenge ROS (Reactive Oxygen Species). Thus, protecting the seeds from lipid peroxidation and oxidative damage of membrane phospholipids rendering seed longevity [18]. There are also reports of proline accumulation and glycine production in primed rice seedlings acting as an osmotic agent, radical scavenger and increasing GSH synthesis respectively, thus protecting the plants from oxidative damage of cold stress [16]. β -mannanases activity has been increased on priming which weakens endosperm layer and allows radicle to emerge, therefore breaking thermodormancy [7]. Priming also maintains cell division and structure (cytoskeleton) by abundant synthesis of alpha and beta tubulin subunits [15].

III. TECHNIQUES OF PRIMING

Nowadays different priming techniques are developing to provide better seed quality such as hydro-priming, halo-priming, osmo-priming, matrix priming, osmohardening, on-farm priming, hormone or growth enhancer priming, micronutrient seed priming (Nutripriming), biopriming or seed treatment with micro-organisms, e.g. *Pseudomonas aureofaciens*, *Trichoderma* spp. etc and nanoparticle priming or coating seeds with nanoparticles (NPs). Each crop requires specific and optimised priming technique. Optimisation includes various parameters such as time required for treatment, priming or coating substance, seed vigour and storage conditions (temperature, moisture, oxygen requirement etc.) which are standardised by trial and error for each cultivar [17].

1. Hydro-priming

Hydro-priming is a technique which uses water to soak seeds, drying it for dehydrating and then sowing the next day. This leads to increase in process of germination, accelerates seedling growth and strength [10]. [5] carried out hydro-priming of aged chickpea seeds and found increased rate of germination and dry weight of seedling. Priming

increased quantity of grains/plant/unit area from low vigour seeds on comparison with high vigour seeds and also restored the quality of aged and damaged seeds enhancing the production in field. It also increased germination percentage and seedling emergence which cause productive use of resources (soil, light) to increase the amount of grains. Decrease in seed vigour is an indication of electrolyte leaching due to an increase in membrane permeability. Electrolytes such as inorganic ions, amino acids and sugars are leached, which have high impact on metabolism and different activities involved in synthesis causing decrease in germination and overall growth of seedling. Priming seeds might have repaired seeds by reducing electrolyte leakage, repair of biomolecules such as DNA, RNA, proteins, enzymes and membranes. Similarly, [11] have evaluated the effect of different priming methods such as osmo-priming, hydro-priming (Zinc sulphate with 100 mM Zn and Monopotassium phosphate with 50 mM P) and halo-priming (1% potassium nitrate solution) on corn. Good results in terms of metabolic processes, higher germination percentage and rate, seed yield and yield components were seen in primed seeds. Hydro primed seeds showed maximum results suggesting that ion accumulation in the seed has no toxic effect on the embryo. This treatment thus can be used to increase tolerance in drought condition and enhance growth leading to environment-friendly technique for improving crop yield.

2. On-farm priming

On-farm priming involves hydrating seeds to around 12 hrs [8], 17 hrs in semi-arid tropics, 8 hrs or overnight [10], surface drying and then sowing the following day. Huge benefit in crop yield was obtained by [10] using same technique in chickpea.

3. Halo-priming

Halo-priming is a technique which involves submerging seeds in solutions of inorganic salts viz. sodium chloride, potassium chloride, potassium nitrate, calcium chloride etc. Some of these salt solutions may exert direct or indirect nutritional effects. Many studies have been undertaken using halo-priming technique to improve seed germination and crop yield in alkaline soil. [19] has evaluated the response of germination in 4 cultivars of sunflower seeds (*Helianthus annuus* L. cultivars) and its seedling growth on priming with sodium chloride and potassium nitrate in alkaline environment. Primed seeds increased seed germination, sturdy seedlings and produced large quantity of plants/unit area. However, there was decrease in germination percentage and seedling appearance in seeds (both treated and untreated) as NaCl salinity increased, but in primed seeds, the decrease was less. Similarly, [13] and [20] showed increased germination as well as growth parameters in Tunisian coriander seeds primed with NaCl and CaCl₂ and safflower (*Carthamus tinctorius*) seeds primed with NaCl and KCl

respectively compared with unprimed seeds. Again, it is seen that [21] reported that treating maize seeds with NaCl and sowing under normal and saline conditions improved performance of maize plants under field and laboratory conditions. It is known that salinity adversely affects plants by reducing root growth, leaves and dry weight of aerial parts as it interferes in phytohormone biosynthesis, its mode of action, which ultimately reduces photosynthesis and overall plant production and biomass. Priming might have enabled the seeds to absorb water effectively, homogenise germination in less time, lead to earlier metabolic activities in seed germination and could also stimulate enhanced germination via cell division, ultimately enhancing growth in plants. It might have reduced the negative impact of salt stress leading to improved weight of shoots and roots. Also, [12] have shown tolerance to salinity by enhancing K⁺ and Ca²⁺ accumulation, reducing Na⁺ accumulation and efficient osmosis regulation due to organic solutes like proline accumulation in primed seeds.

4. Osmo-priming

Osmo-priming involves soaking seeds in solution of osmotic priming material for a certain period followed by air drying before sowing. Osmotic solutions used are of less water potential so that water uptake is restricted. Various osmotic priming agents such as sugar, polyethylene glycol (PEG), glycerol, mannitol, sorbitol and specialized vermiculite compounds are used, of which PEG is mostly preferred. [22] assessed the outcome of irrigation and priming on growth and grain yield in rice. Priming was done with calcium chloride, *Moringa* leaf extracts (MLE) and potassium chloride, whereas hydropriming technique was used as control. It was observed that MLE primed seeds showed higher yield followed by calcium chloride and potassium chloride primed seeds. Increased growth can be a result of MLE which is an abundant source of growth regulators (ascorbate, zeatin, Ca, K) and are able to enhance metabolites (reducing sugars, amylase). Also the increased quantity and quality of grains might be due to proper mobilization, transport and compartmentalization of food reserves to the developing grains. Likewise, [9] showed that *Bromus* seeds primed with PEG 6000 enhanced germination and produced longer roots as compared with hydro-priming and unprimed seeds. PEG 6000 being inert in nature and able to maintain uniform water potential may be involved in imbibing water rapidly, reviving seed metabolism, increasing germination rate and reducing inherent physiological heterogeneity in germination.

5. Osmo-hardening Osmo-hardening involves soaking seeds in tap water for 24 hrs, re-drying the seeds which are followed by hardening seeds with CaCl₂ and KCl solutions. A study was done by [8] for assessing effect on direct seeded rice using three priming treatments (osmo-hardening, hydro-priming and on-farm priming). Between these three

treatments, osmohardening with CaCl₂ proved to be better followed by KCl. There was an increase in crop yield due to enhanced growth, large quantity of tillers, enlarged length and yield of kernels, increased contents of K, P and Ca, whereas reduction was seen in unproductive kernels and unwanted ineffective spikelets. Increase in crop yield could be an effect of improved nutrients, their uniform distribution and transport of photoassimilates in the direction of kernels.

6. Hormonal priming

Hormonal priming refers to treating seeds in hormones such as GA₃, salicylic acid, ascorbate, kinetin, jasmonic acid etc. which helps in promoting seedling growth [12]. Gibberellic acid priming influence on growth and biochemical parameters of chickpea DCP 92-3 cultivar was studied by [23]. Chickpea seeds primed with four different concentrations of GA₃ showed significant increase after 90 and 100 days of sowing with best results obtained at 10-6 M concentration soaked for 8 hrs. Biochemical (protein content, carbonic anhydrase (CA) activity) and growth parameters (seed yield and leaf area/plant, pod number and shoot length) were also enhanced. Gibberellins are known to regulate developmental and physiological processes such as germination, stem, leaf growth, synthesis of food, transporting and partitioning it, stimulating transcription of hydrolytic enzymes' mRNA in various plants. CA enhances membrane permeability and nutrient absorption. Similarly, [24] investigated the outcome of lucerne seed primed by brassinolide for parameters such as emergence and growth under salt stress. Germination percentage and vigour index was remarkably greater and also CAT, POD and SOD activities were increased in primed seed varieties compared with unprimed seeds.

On the contrary, [1] studied that antioxidant enzymatic activities were not induced on priming with hormones such as salicylic acid, methyl jasmonate and ethylene in maize seedlings under salt stress. But ethylene priming could enhance biomass, as it is known to trigger tolerance mechanisms throughout seedling establishment. However, [25] observed increased germination parameters, decreased time of germination, enhanced plumule, radicle length and dry weight in 2 inbred lines along with decrease in MDA content on chitosan priming. Also there was increase in concentration of gibberellic acid, IAA, lipase activity, proline and soluble sugars, POD and CAT activity which are involved in enhancing growth of plants. Chitosan (large cationic polysaccharide) acts as a biostimulator which stimulates various vital processes in plants at physiological, biochemical and molecular levels. This suggests that chitosan may improve germination speed and growth of seedling under low temperature stress. In the same way, [26] also reported that chickpea seeds treated with β - estradiol and progesterone caused various biochemical changes in seeds stimulating germination and growth. These hormones

accelerated changes by decreasing the final product of lipid peroxidation, MDA content and increasing antioxidant enzymes which detoxify ROS that leads to oxidative damage.

7. Matrix priming

Matrix priming refers to incubating seeds in a matrix/polymer (solid and non-soluble) with restricted water use. Examples of matrix are sand, vermiculite etc. Sand matrix improved germination parameters up to 50%, whereas carrot seeds showed better response for hydropriming method in an experiment conducted by [17]. In this experiment, 4 methods viz. hydro, sand matrix, halo and osmopriming were set, of which sand matrix priming was done by mixing water and sand to achieve specific water holding capacity. Based on this study, it can be concluded that each method and crop species requires specific duration and concentration to be determined for proper development and growth.

8. Nutripriming

Nutripriming involves priming seeds in solution of nutrients to improve seed quality by increasing nutrient content of seeds. Micronutrients are important for plant growth as they carry out two vital processes in plants namely photosynthesis and respiration whose limitation can decrease the overall growth and grain yield [27]. To cope up with this problem, micronutrients can be used in three ways such as applying it to soil, spraying on leaves/plant or directly applying to seeds. Amongst them, seed treatment has been proved better option to improve seedling growth and grain yield as less micronutrient will be needed. [4] performed an experiment for evaluating the outcome of iron and boron seed priming individually and in combination on dill (*Anethum graveolens*). He worked on a range of concentrations (0.5 to 2%, with a difference of 0.5%) individually and in combination (1.5% iron plus 1% boron) and found that there was significant increase in percentage of germination, seed and essential oil yield and seedling vigour index on priming seeds with 1.5% iron plus 1% boron, whereas seedling vigour index was restricted on increasing the concentration of iron beyond 1.5% and boron beyond 1%. Due to high germination rate, uniform stand establishment and high seed yield, essential oil yield was also enhanced in primed seeds as compared to unprimed seeds but high concentrations had no significant growth. Similarly, [28] also showed results in accordance with [4] that high concentrations of boron are toxic to seeds and may slow the establishment of Broccoli seedlings. However, seeds primed with low concentration of boron promoted length of shoot, root and fresh and dry weight. Priming with micronutrients enable seeds to uptake water at a faster rate and encourages it for different metabolic processes. Boron as already reported is known to activate key enzymes such as phosphorylase, α -amylase etc. which might stimulate cell elongation, meristematic growth and increase chlorophyll content leading to overall growth.

Likewise, positive results were seen by [29] on priming wheat and chickpea seeds with zinc, whereas [30] observed reduction in yield at high concentration of zinc but increased seed yield, pods/plant and dry matter production on combined treatment with zinc, molybdenum and boron. In the same way, [31] and [32] also reported enhanced number of leaves, plant height, total yield and dry matter, nodule number and leghaemoglobin content on priming pigeonpea and peanut seeds with cobalt nitrate and increased copper, potassium and manganese content in grains and grain yield on priming wheat seeds in copper sulphate or manganese sulphate respectively. Some of these nutrients are directly involved in photosynthesis, thus increasing the biomass whereas some (Mo, Co and Cu) are involved in nitrogen fixation by legumes and nitrogen metabolism, whose deficiency may cause adverse effects on plant growth.

9. Bio-priming

Bio-priming involves treatment of seeds with beneficial micro-organisms. Micro-organisms which protect plants from pathogens and improve their growth are used. [33] observed that *Azospirillum brasilense* and *Pseudomonas fluorescens* primed seeds increased plant parameters such as leaf number, length of roots, height and content of ajmalicine in *Catharanthus roseus* varieties compared with control. Combined effect of both organisms was more significant compared to individual effect on *C. roseus* varieties. Likewise, [34] also found that barley seeds primed with *Azotobacter*, *Azospirillum* and its combination (*Azotobacter* + *Azospirillum*) could increase plant and spike height, spike number/area, grains/spike, thousand grain yield and weight, especially *Azospirillum* showing appropriate performance compared with others. Similar experiment was performed by [35] on maize hybrids using same organisms where positive effect on growth, yield, kernel number/ear and grain number/ear row was seen with significant performance by *Azotobacter*. These plant growth promoting rhizobacteria show beneficial effect as they have the potential to produce growth hormones (GA3, IAA), help in nitrogen fixation, produce antibiotic enzymes against pathogens, solubilise minerals and help in its absorption by roots. [36] studied the effect of coating polymers and antagonistic microorganisms (*Beauveria bassiana*, *T. stromaticum*, *T. polysporum*, *T. viride*, *Metarhizium anisopliae*), mycorrhizas, amino acids, plant growth regulators (PGRs) and micronutrients together on sweet pepper seeds. Primed seeds increased the emergence and development of seedling along with increased dry matter of roots. Also number of nodules, nitrogen uptake and total yield was enhanced in green gram seeds treated with *Rhizobium* culture and micronutrients (molybdenum and cobalt) compared with control when grown in moderate acidic soil [37]. Such seed treatments promote germination through environmental signals, mRNA activation/depression, membrane permeability and effect on pathogens.

These studies are noteworthy in increasing production, but still, this technique is not routinely used due to inconsistent results. Thus, there is need of deeper research to standardise such technology to yield expected results and use it commercially.

10. Nano priming

Nano priming is a new method of seed priming with nanoparticles (NPs) such as zinc oxide, iron oxide, titanium dioxide, silver nanoparticles etc. Fertilizers or nutrients applied to plants are not utilized by them as they get drained away or are broken down by exposure to light and water. Nanoparticulate material/nutrient delivery to plants provide adequate and restricted use of nutrients/ macromolecules at a specific site required for enhancing plant growth[38]. [39] had conducted a laboratory study to determine the inhibitory or stimulatory effect of nano-sized Ag, Cu, and Fe on wheat. Germination percentage and root-shoot length were enhanced with iron NPs whereas Cu showed inhibitory effect on growth indicating iron to be stimulatory and copper as inhibitory. Similarly, [38] also observed positive and enhanced results of iron NPs on growth of BARI Gom 25 wheat seedlings at 2ppm whereas negative impact was seen at 2.5 ppm, indicating higher dose of iron oxide to be toxic for germination and seedling growth. Iron oxide proves to be a source of iron for plant development and synthesizes siderophores. Iron stimulates plant growth by activating several enzymes, RNA synthesis and improving the performance of photosystems in plants. Effect of silver nanoparticles (Ag NPs) were studied by [40] on wheat and barley seeds, [41] on corn, watermelon, zucchini seeds and [42] on fenugreek seeds. There was increase in percent germination, seedling growth, shoot length, chlorophyll content and antioxidant enzymes whereas decrease in root length and biomass at higher concentrations. Root tips were damaged at nuclear level (i.e. deformities) and chromosomal (i.e. abnormal number of chromosomes, fragmentation, and deletions) in germinated seeds, indicating the ability of Ag NPs to invade plant cells and damage cell division stages leading to abnormalities in chromosomes. Hence, dose of nanoparticles need to be standardised for each crop.

[43] had investigated the effect of Titanium dioxide nanoparticles (N-TiO₂) on germination of fenugreek seeds synthesized biologically from *Aspergillus niger*. Primed seeds showed an increase in biochemical parameters such as proteins, carbohydrates, chlorophyll, and reducing sugars compared to control. Similarly, [44] also concluded with the same outcome on pepper (*Capsicum annum* L.) seed germination using anatase nanoparticles (TiO₂). Enhanced biochemical parameters may be the effect of translation process increasing protein level, improved electron transport, photosynthetic efficiency and ribulose-1, 5-bisphosphate carboxylase/oxygenase activity leading to carbohydrate synthesis, and electron transport chain leading to increased

pigments and chlorophyll content. This may have led to enhanced photosynthesis and nitrogen metabolism ultimately improving seedling growth.

[45] studied the effect of nanoscale zinc oxide (ZnO) and chelated bulk zinc sulphate (ZnSO₄) on peanut seeds. It was observed that 1000 ppm concentration of nanoscale ZnO improved growth as compared to chelated bulk zinc sulphate by promoting seed germination, seedling vigour, earlier adaptability, growth, flowering, chlorophyll content, root shoot length and pod yield per plant, however, higher concentration of 2000 ppm had negative effect on growth. Similar results were observed by [46] in onion where flowering duration was reduced by 12-14 days at low concentration but phytotoxic effects at high concentrations were seen. Also, [47] observed the effect of seed polymer coating of Zn and Fe NPs at different concentrations in pigeonpea. Higher seed germination, seedling growth, field emergence, seedling vigour index, dehydrogenase and amylase activity were observed at lower concentration of Zn and Fe NPs over their bulk forms and control, whereas seed germination and seedling growth was inhibited at higher concentrations. Zinc is an essential component of different enzymes which helps in starch and protein synthesis, their metabolism, cell elongation, maintaining cell membrane strength and function, seed maturation as well as tolerance to environmental stresses. Enhanced germination due to nanoscale NPs over bulk might be due to its nano size which allows them to penetrate through the seed coat easily and provide better absorption and utilization by seeds, produce essential biomolecules and quench free radicals in germinating seeds. But higher concentration decreased germination probably due to increased absorption and accumulation of NPs inside the cells causing reduction of cell division, cell elongation, and inhibition of hydrolytic enzymes required for food mobilization during the process of seed germination. [48] worked on Lettuce, Cucumber and Radish seeds to examine the biological impact of NPs on seed germination and root elongation. He found that CuO and NiO had deleterious effects on all the three seeds. Co₃O₄ improved root elongation of radish seedling, whereas phytotoxic effects of TiO₂, Fe₂O₃ and Co₃O₄ were not significant.

IV. BENEFICIAL EFFECTS OF PRIMING

1). Priming exhibits uniform and faster germination rate, seedling vigour and crop establishment under adverse conditions. 2). Priming overcomes thermodynamic. High temperatures (35°C) inhibit accumulation of free amino acids and esterase activity required for radicle protrusion, which can be reversed by seed priming with kinetin leading to germination [49]. In lettuce seeds, as endosperm covers the embryo, so for radicle protrusion, this endosperm is weakened by endo β-mannanase which requires ethylene for

activation. At high temperatures, germination is reduced as ethylene production is inhibited, in turn reducing the activity of endo β-mannanase. [7] reported that osmopriming of thermosensitive lettuce DGB seeds with PEG or PEG + ACC could overcome thermodynamic and improve germination at 35°C - 40°C. 3). Seed priming of different crops can alleviate the adverse effects caused by stress (drought and salt) and enhance crop yield [3, 9, 20]. 4). Priming ameliorates chromosomal damage induced by aging. 5). It reduces the soil-borne destructive diseases. Seed priming using *S. mukorossi* and *A. Nilotica* leaf extract was effective in controlling infection with root rot fungi like *Macrophomina phaseolina*, *Fusarium spp.* and *Rhizoctonia solani* in okra, sunflower, peanut and chickpea seeds [14]. Chickpea primed seeds showed less incidence of soil-borne disease compared with non-primed [10]. 6). Priming also enhances viability of low vigour seeds. Seed deterioration occurs by the formation of free radicals which are generated on peroxidation of unsaturated membranous fatty acids leading to harmful effects on cell membranes and related subcellular components by accelerated aging. [18] reported that osmoconditioning in sorghum aged seeds induce enhanced production of enzymatic activities such as POD and CAT, thereby protecting the seedlings against oxidative damage.

V. NEED OF RESEARCH

The toxicity of NPs depend upon plant species, size of NP (smaller NPs have high surface area being more toxic), seed size (small seeds being more sensitive) and the ability of NPs to adsorb on seed surface for freeing ions. Hence, there is need of research to find the appropriate nanoparticles, their concentrations and its effect on specific crop. Also research needs to be done on how to avoid use of herbicides which not only acts against weeds but also hampers the crop growth. Can nanoparticles solve this problem? There are various environmental issues such as climate change, urbanisation etc. which has severe impact on agriculture. Here lies a scope where nanotechnology can be a boon. Considering the positive and negative impact of metal oxide NPs on plant species, it may hold significant potential applications in agriculture which may inhibit unwanted plants, kill harmful fungi and bacteria and release essential metal elements for plant growth. Also biopriming with plant growth promoting rhizobacteria can increase overall development of crops by stimulating synthesis of growth promoting substances, making available the insoluble phosphates by solubilizing, enhancement in stress resistance and systemic disease resistance [50]. Thus, the use of metal oxide nanoparticles and plant growth promoting rhizobacteria together for seed priming i.e. Bionanoseed priming can be an attempt to produce a technology that could be used with higher security for increasing plant productivity in future.

VI. CONCLUSION

Seed priming enhances germination, leads to early flowering and maturity, breaks dormancy and makes the crop resistant to abiotic stresses and soil-borne destructive diseases by inducing systemic resistance. It is clear that use of different priming techniques has been studied on varied crops and found to be beneficial in terms of crop yield. So, seed priming can be considered as a better solution against problems related to germination when seeds are grown under unfavourable conditions. A study on priming techniques revealed that each technique in some way improves growth and yield of crops, but require standardisation as various factors need to be considered. Also, it is seen that biopriming using PGPRs not only helps plant growth but also restores the soil microbiota. Further, nanopriming is gaining importance due to controlled release and site-directed delivery of nutrients or agrochemicals. Hence, an attempt to amalgamate nanofertilisers and PGPRs for priming seeds (bionanoseed priming) can prove to improve crop productivity in near future.

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