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Mini Review Article

Seed priming: An innovative approach to enhance seed quality in legume crops

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ABSTRACT

Seed priming is being applied in agriculture on different crops for resolving adverse biotic and environmental situations, protecting crops, and prolonging the viability and storability of the seed. Seed priming with various priming agents including tapwater, several salts (KNO_3, $MgNO_3$, $Mg(SO_4)_2$, KCl, $CaCl_2$, K_2PO_4, KH_2PO_4 and PEG) and plant growth promoting substances like GA_3, IAA, NAA, kinetin, ascorbic acid, nutrients as Hoagland solution, urea and ethephon etc. have been used in varying concentrations in different legume crops including pulses. Seed priming has beneficial effects on seed quality enhancement, plantstand, growth, yield attributes, and finally yield and seed recovery percent in crops. In addition, the seed priming also positively influenced the activities of nitrate assimilation enzymes, viz.nitrate reductase and nitrite reductase,which facilitate the availability of NO_3 to the growing seedlings. In pulses, these priming agents, especially KNO_3 and $MgNO_{3,}$ increase the activity of the nitrogenaseenzyme and increase the rate of nitrogen fixation with the help of Symbiotic bacteria. Priming agents like GA_3, IAA, NAA, kinetin, and ascorbic acid induce the activities of germination enzymes like alpha amylase, protease, and lipases, that's after hydrolyzing, make available the stored seed reserves to germinating seedlings. This review describes how seed priming enhances pulse crop germination, seedling establishment, growth, and yield.

***Key words*: Enzymes, Germination, In-organic salts, Seed, Priming, Seedling, Vigor, Priming agents, Yield attributes**

INTRODUCTION

Seed is the most important determinant in effecting productive agriculture, on which the efficacy of other agricultural inputs is dependent. The majority of growers used traditional and poor methods of seed storage, which results in the deterioration of seed viability and storability, causing poor germination, vigor, and plant stand in several crops. Seed quality enhancement techniques, including seed priming, seed pelleting, seed film coating, and seed coloring, are being applied in agriculture on different crops as reported by several workers for tackling adverse biotic and abiotic situations, protecting crops, and prolonging the viability and storability of seed.

Any post-harvest treatment that improves germination/seedlings emergence or facilitates the development of a greater number of normal, rapid, uniform, and healthy seedlings in the field conditions is termed seed enhancement (Donald 2000). There are two goals of seed enhancement: (i) seed functioning and (ii) seed designing, which can be achieved by using seed enhancement technique. It has following two categories: (i) Seed Invigoration or Priming which including osmo-priming, hydro priming, solid matrix priming, halo priming, bio-priming and drum priming and (ii) seed coating that includes seed film coating, seed coloring and seed pelleting.

SEED INVIGORATION

Seed invigoration or priming is a treatment in which seeds are soaked in an osmotic solution/ other solutions containing different active ingredients, which allows water imbibitions and permits early stages of germination but does not permit radical protrusion through the seed coat (Heydecker 1973). In priming osmotic potential of the solution is lowered due to solute accumulation in the embryo, which might generate sufficient turgor pressure to overcome endosperm/seed coat restraint (Bradford 1986).

Osmo-priming

Soaking the seed in osmotic solutions is osmo-priming. In this process, germination is regulated by manipulating temperature, seed moisture content, and duration. Water is either made freely available to the seed (as in steeping or soaking) or restricted to a pre-determined moisture content, typically using water potential between – 0.5 MPa and -2.0 MPa. Several osmotic-like, inorganic salts, chemically inert compounds such as PEG-6000, PEG-8000, mannitol, and plant growth regulators like IAA, IBA, NAA, GA_3 and Kinetin and nutrients in the form of complete nutrient solution/Hoagland solution containing all macro and micro nutrients essential for plant growth are used in osmo priming.

Hydro priming

Hydro priming is the soaking of seed in water for a specified period to induce the primary stages of germination. The period of hydro priming varies from species to species, depending upon the hardness or softness of their seed coat eg. wheat and rice 10 to 12 h, pulses 6 to 8 h.

Solid-based matrix priming

Pre-sowing hydration in a solid-based medium is called solid-based matrix priming, and it is used for increasing the efficiency of fungicides/ insecticides to control the seed borne infection and soil insects. In solid matrix priming, seeds slowly imbibe to reach an equilibrium hydration level, determined by the reduced matrix potential of the water adsorbed on the particle surfaces.The solid-based medium used is mostly vermiculite, peat moss or charcoal along with a known amount of water.

Bio priming

Coating the seed with biological agents like *Rhizobium* culture and *Trichoderma* etc., to protect the seeds from pests during storage and in the field.

Drum priming

The hydration of seeds throughout 24-28 hrs in a drum revolving at 1-2 cm/sec. is termed as drum priming, and in this process, mixing of the seeds should be uniform, and the seeds at the end of the treatment are plumbed and dried. A preset volume of water is injected during each cycle as regulated by an attached timer.

Seed hardening

It is a process of soaking seeds in water for a precise period, followed by drying and re-soaking and re-drying. This process of alternate hydration and dehydration cycles with water and later drying to the original moisture is called seed hardening. Here, it is the dehydration on the cycle, that is responsible for the hardening of seeds.

Dry seed

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Soaking in water and/or dilute solution of GR and chemicals for (1-12h at 15-25 ^{0}C)

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Shade drying (1-24 hrs)

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Sun drying (1-2 days) to bring it back to its original water content or weight

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Hardened seed

ADVANTAGES OF PRIMING

- Faster emergence and a more uniform field stand in normal as well as in stress conditions.
- Uniformity, synchrony, and significant yield increase in many vegetable crops.
- Primed seeds can be rinsed and dried for storagefor short periods in several crops.
- Effectively overcome the serious problem of soaking injury in many legumes.

LIMITATIONS

- This is expensive seed treatment, so not very feasible for big seed lots.
- Causing ill effects of anaerobic respiration in seed lots when the priming period is longer.
- The chances of an attack by a micro organism are higher in seed lots.

The following beneficial effects have been observed whenpriming is followed by drying for seed hardening.

- Accelerates the rapid germination and growth rate of the seedling
- Treated plants recovermuchmore quickly from abiotic stress than untreated plants.
- Flowering is slightly accelerated.

- Induces tolerance to salinity/alkalinity and drought.
- Seeds can with stand high temperature [80-105^{0}C) for a prolonged period (24-46 hrs).

EFFECTS OF SEED PRIMING ON SEED QUALITY PARAMETERS AND CROP PERFORMANCE

Presoaking of soybean cultivars in water for 24 hours had a significant effect on germination and seedling fresh weight. The increase in germination percentage ranges from 21.20 to 54.00, and seedling fresh weight from 1.735 g to 3.445 g. (Nalawadi *et al*. 1973). Seed treatment of tomato seeds with GA_3 (10, 100 ppm) and KNO_3 (0.1 M) at 26°C for 14 days increased the germination rate, and GA_3 induced an increase in sugars, protein hydrolysis, and RNA (Earl Puls and Lambeth,1974). In groundnut, when seeds were treated with one per cent calcium chloride for eight hours, the yield increased with high free proline accumulation, which is an adaptive mechanism of drought tolerance (Sashidhar *et al*. 1977). Christiansen and Foy (1979) found that seeds primed with calcium salts recorded higher germination and membrane integrity and concluded that calcium salt concentration in seeds and germination percentage were positively related, suggesting the role of calcium as an important component in membrane stabilization and as an enzyme cofactor. The positive effect of seed priming with potassium and distilled water ongrowth, dry matter accumulation, grain and straw yield in chickpea in Bangladesh was reported by Musa *et al*. (1999). Soaking of groundnut (JL-24) seeds in 0.50 per cent $CaCl_2$ solution for 32 hours followed by 10 hrs drying resulted in higher germination (98 per cent), field emergence (92.00 per cent), vigor index (3372), and oil content (50.72 percent), compared to water soaking (77.00 per cent, 91060, 3007, and 47.19 per cent) as reported by Subbaraman and Slevaraj (1989**.** Improvement in germination, shoot/root length seedling dry weight and finally in vigor index by seed priming with tap water and inorganic salts (KNO_3 and Mg $(SO_4)_2$) is might be due to induced large free space between embryo and endosperm in primed seed which is deemed to play a role in accelerating germination rate by facilitating more uptake of water (Argerich and Brad ford 1989). Presoaking of high vigor seed lot of soybean in water for 12 to 14 hours followed by drying ensured significantly higher plant height (54.00 cm), leaf area index (2.19), number of pods per plant (32.00), hundred seed weight (12.40 g) and seed yield (2.40 t ha^{-1}), compared to low vigor seed lot (50.00 cm, 2.15, 28.00, 11.85 g and 2.10 t ha^{-1}, respectively) as reported by Rama Rao and Gopel Singh (1991). Among various treatments, the water soaking showed significantly higher yield (455 kg ha^{-1}) compared to soaking of seeds in urea (441 kg ha^{-1}), P-Amino benzoic acid (447 kg ha^{-1}), tannic acid (384 kg ha^{-1}) and control (326 kg ha^{-1}) as reported by Dharamlingam and Basu (1993). Similarly, Rangaswamy *et al.* (1993**)** conducted a laboratory experiment with groundnut seeds and reported that soaking the seeds in 10 per cent KH_2PO_4 solution slightly increased the germination per cent, vigor index, and root-shoot ratio. The priming-related increase in the biomass and grain yield of mungbean was due to a combination of better emergence and better performance per plant as reported by Parera and Cantliffe (1994). Seeds of groundnut soaked in water significantly increased the yield (18.23 q ha^{-1}) over the control (15.61 q ha^{-1}), the oil percent was also significantly higher in soaking of seed in water (43.90 percent) over control (42.40 percent**)** as reported by Naphade *et al.* (1996). Qingxiang *et al.* (1996) reported that GA_3 and kinetin stimulated corn and soybean seedling emergence and improved corn and soybean seedling development; GA_3 was more effective than kinetin at promoting seedling emergence and development of corn and soybean; of the concentrations tested, 0.1 mM was the most effective. Feng *et al*. (1997) reported that the application of GA_3 to soybean seeds accelerates germination and seedling emergence.

Maske *et al.* (1997) reported that exogenous application of GA_3 to record a higher speed of germination may be due to its stimulation effect in the formation of enzymes which are important in the early phases of germination, helping for a fast radicle protrusion and hence hypocotyl elongation. Rao and Sing (1997) found that **s**oaked soybean seeds with germination capacity of 90, 70, and 50 % in water or different solutions or conditioned in moist sand before drying back to their original moisture content of 8% sown in *Kharif* gave better growth and yield from seeds with high vigor. Performance of cultivar Savanna of tendergreen, a type of green bean, which had low seed quality, was satisfactory only at osmotic potential of less than - 0.05 MPa, while UFV 10, Doko RC, and IAc 8 gave satisfactory performance up to -0.1 MPa. At -0.6 MPa, seed germination and vigor were not significant in all cultivars (Braccini and Magurie 1998). Narayanswamy and Shambulingappa (1996) reported that soaked seeds in $CaCl_2$ (0.50 percent) and KH_2PO_4 (0.50 percent) showed significantly higher 100 seed weight (41.18 and 37.58 g) and graded pod yield (16.14 g and 1349 kg ha^{-1}), compared to the control (32.35 g and 1260 kg ha^{-1}), respectively. Improvement in germination and emergence performance of primed seeds of the legumes might be due to the repair mechanism, mobilization of storage reserves for utilization during germination and dormancy breakdown (Hocart *et al.* 1990). Bose and Mishra (1999, 2001) opened that during soaking of seed in $Mg(NO_3)_2$ or KNO_3 solution the cations Mg^{++} or K^+ and anions NO_3 in fluxed in the seeds and showed their carry over effect during vegetative growth period and consequently the yield was increased and it was also supported by Bose and Pandey (2003). Massawe *et al*. (1999) observed that hydration for different duration in three cultivar of Bambara groundnut significantly increased the germination per cent (49.00 to 74.00), seedling emergence (42.00 to 72.00), and dry weight (160 to 250 mg), unsoaked seeds started germination six days after sowing while hydrated seeds started germination on the fourth day. Irfan *et al.* (2004) found that invigorated seeds of soybean cultivar JS-335 having initial germination of 72 per cent with different chemical solutions for three hours; KH_2PO_4 (2%) could enhance germination up to 88 per cent and was found superior in maintaining seed viability and vigor and increased yield, maximum root and shoot lengths were recorded in hydro primed seeds. Aldesuquy and Ibrahim (2000) reported that seed treatment with shikimic acid improved yield and yield components of cowpea plants by increasing the number of pods $plant^{-1}$ and the number of seeds pod^{-1}. Similar results were reported by Basara *et al*. (2003) and Rashid *et al*. (2004) that primed seed plants produced more grain pod^{-1}, and the germination time was on average, reduced by 2-3 days by primed seeds. Andredi and Leon (2000) explained that during matriconditioning of legume seeds,germination is suspended, providing a unique means to rapidly digest the endosperm by GA_3-induced enzymes and reduce the mechanical restraints of endosperm, thus providing energy to start and sustain embryo growth.

Murungu *et al*. (2004) observed that onfarm seed priming of mungbean performed better under different soil physical environments compared to non-primed seed. Rashid *et al.* (2004) reported the effect of onfarm seed priming on improving the yield of mungbean. Benefits from priming were the result of a combination of faster germination and emergence and more vigorous growth and development, leading to better crop stands and bigger, more productive plants. Yogananda *et al.* (2004) concluded that, whatever the mechanism responsible for the beneficial effects of seed priming, the empirical evidence confirmed its effectiveness for mungbean, and the practice should be tested by and promoted with all farmers who wish to grow mung bean. Pre-sowing hydration treatment significantly enhanced field emergence (79.77 per cent), rate of germination (32.59) and seedling dry weight (3.92 g) of parental lines in soybean hybrid seed production compared to control (61.90 per cent, 29.27 and 3.73 g, respectively) in both seasons, where in the treatment effect was more evident in winter season (Basu and Choudhary 2005). Two experiments were conducted to determine the possibility of increasing the germination of soybean varieties through seed priming. The study concluded that priming soybean seed could be recommended where soil water potential is low enough to limit emergence (Murungu *et al.* 2005). Arif (2005) analyzed two years' average data, indicating that soybean plants of primed seed plots took fewer days to emerge, flower, and mature as compared with plants of non-primed seed plots. Primed seed plots produced more plants m^{-2}, taller plants and higher grain yield as compared with non-primed seed plots. Days to emergence and maturity increased with an increase in seed priming duration. Rashid *et al*. (2006) reported that priming enhanced germination, better establishment, and increased yields in a range of crops in many diverse environments. The priming technique due to its simplicity, might be acceptable to the farmer of area as accepted to farmer in other semi-arid region and promoted to a wide range of crops, for example maize (Harris *et al*. 2007), wheat (Harris *et al*. 2001), mungbean (Rashid *et al*. 2004), chickpea (Musa *et al*. 2001), upland rice (Harris *et al*. 2002) and millet (Kumar *et al*. 2002). Verma *et al.* (2006) reported that both fresh as well as one-year-old mung bean seeds were soaked in $CaCl_2$ (2%) for 16-18 h, and recorded a significant increase in germination, seedling dry weight, and rapid and uniform field emergence compared to the control. Priming of mung bean seed with phosphorus (P at 0.6%) was found very effective for improved germination and vigor of mung bean seeds under field conditions. It is an easy and cost-effective technology for resource-poor farmers of the region (Adnan Umair *et al*. 2011).

Afzal *et al.* (2011) observed that increased shoot and root length of primed seeds as compared to controls might be due to an increased rate of cell division in the root tips and an earlier start of emergence as observed in the wheat crop. Orzesko and Podlaski (2003) reported that priming with calcium chloride made the nutrients available to the plants, hence, causing extensibility in the cell wall of the sugar beet roots and an increase in seed respiration intensity. Priming of mung bean seeds with inorganic salts like KNO_3, $Mg(NO3)_2$ and Mg SO_4 in 30 mM concentration for 12 hrs significantly enhanced the seed quality parameters, yield attributes and yield of mung bean crop over unprimed control, the performance of $Mg(NO3)_2$ was superior over other salts in all traits studied (Tiwari *et al*. 2013). Seeds of pigeonpea varieties like NDA-1, Bahar, LRG-30, UPAS 120, TS30, and Pusa 2002-2, when primed with 0.30% KNO_3 for 06 hrs, significantly enhanced the seed quality parameters, yield attributes, and yield in all the varieties evaluated over unprimed controls. The concentration of 0.30% KNO_3 was found superior for seed quality enhancement over 0.4 % and 0.5% KNO3 tested in the study (Tiwari *et al*. 2014). Mung bean seeds of Pusa Vishal and Samrat varieties primed with 100 ppm solution of plant growth regulators, including GA3, IAA, IBA, and Kinetin, separately for 8 hrs, significantly enhanced the seed quality parameters over unprimed control. Amongst the PGR, the performance of GA3 was superior toothers (Tiwari *et al*. 2015).

The positive correlation between reducing sugars and seedling dry weight suggests that seed priming treatments remarkably improved seedling vigor due to increased starch hydrolysis in calendula (Karimi and Varyani 2016). Seed quality enhancement of common bean (*Phaseolus vulgaris* L.) var. S 9 (local) was reported through bio priming with the biocontrol agents at 40, 50 and 60 % concentration for 4,8,12 and 16 hours of soaking, *Trichoderma harzianum* at 40% concentration and for 4 hours of soaking resulted enhancement of above quality parameter like 13.0% in germination, 21.1% in shoot length, 20.7% in root length, 31.6% in seedling dry weight, 36% in seedling vigor index-I, 48.1% in seedling vigor index-II and 58.6% in speed of germination over unprimed seeds. Bio priming with *P. Fluorescence* (at 40% concentration and for 4 hours) closely followed and at par with the best treatment with 11.6%, 18.2%, 16.4%, 30.4%, 30.7% and 56.9% enhancement of above mentioned quality parameters, respectively (Monalisa *et al*. 2017). Seed priming using various methods viz, hydro priming, helopriming, and osmopriming, bio priming was evaluated by screening a range of duration and concentration viz., T0 Control, hydro priming, osmopriming- PEG (20%), helopriming (KCl 1%), ($CaCl_2$ 1%), bioprming (Neem leaf Extract 5%), and (Eucalyptus extract 5%) for 14 hours. It was found that all the priming methods showed signification difference with the control, and the highest percentage of germination, seedling length, weight, and germination index were observed for PEG priming for 14 hours (Mishra *et al.* 2017). One-year-old pigeon pea seeds when primed with different priming agents such as growth regulator (100 ppm GA_3), inorganic salt (0.2% KNO_3) and tap water separately for 06 hours significantly improved the plant height, number of branches, yield attributes like no. of pods/plant, test weight, biological yield and finally grain yield in two pigeon pea varieties evaluated over unprimed control (Tiwari *et al*. 2019). Mung bean varieties namely Virat, Samrat and Meha primed with 100 ppm GA_3 showed maximum enhancement in germination,root, shoot length and vigor-I where as seed primed with 0.2% KNO_3 showed improvement in seedling dry weight and vigor-II under normal as well as drought condition but the improvement over respective control was higher in drought condition. Amongst varieties, Virat performed better than Meha and Samrat (Tiwari *et al.* 2019). Pigeonpea varieties, namely Bahar and Malviya-13 seeds, when primed with GA_3 (100 ppm), KNO_3 (0.2%) and tap water for 06 hours separately, showed significant enhancement in all seed quality parameters over un primed control. Among the priming agents, GA_3 and KNO_3 were better than tap water (Tiwari and Agarwal 2020). Osmo priming of one-year-old chickpea seeds with KNO_3, $MgSO_4$, and $Ca(NO3)_2$ at 0.2% solution and tap water for 06 hours significantly enhanced the seed quality parameters in both the varieties evaluated under normal and water deficit conditions over their respective control. Amongst the priming agents used, KNO_3 performed better than $MgSO_4$ and $Ca(NO3)_2$ in most of the seed quality parameters studied (Tiwari and Katiyar 2021). Under sodic soil conditions of eastern Uttar Pradesh, priming of chickpea seeds with KNO_3 (0.2%) and GA_3 (100 ppm) for 06 hours significantly improved the seed quality parameters, yield attributes, and yield in both the varieties (BGD-72 and Shubhra) over the unprimed control. Varity BGD-72 showed its superiority over Shubhra in terms of seed quality parameters and grain yield (Tiwari and Agarwal 2021).

In general, pulses are a unique type of crop due to their high content of vegetable protein, an important part of the human diet, and their major contribution to the cropping system through nitrogen fixation. A wide range of physiological deterioration that results in qualitative, quantitative, and economic losses occurs during the post-harvest storage of pulse crops. For pulse crop germination, growth, seedling establishment, and yield, the appropriate abiotic and biotic conditions are required. The article covers the seed priming approach, which can coordinate seed germination and increase vigor for better seedling establishment and productivity. Seed priming turns on metabolic pathways that break dormancy, prevent seeds from degrading, and boost overall resilience to biotic and abiotic stressors. The overall review provided in this paper describes how seed priming enhances pulse crop germination, seedling establishment, growth, and yield (Garai and Patra 2024).

EFFECT OF SEED PRIMING ON ACTIVITIES OF NITRATE ASSIMILATION, GERMINATION AND ANTI- OXIDANT ENZYMES

Nitrate is considered the primary source of nitrogen from the soil. The main function of the enzyme nitrate reductase (NR) is to reduce nitrate to nitrite**.** Beevers and Hugeman (1969) opened that, being an adaptive enzyme, its activity is affected by several internal and external factors. Nitrate reductase activity was readily induced by the addition of nitrate substrate (Afridi and Hewitt 1964) and increased as the concentration of nitrate was increased in the nutrient solution (Hageman and Flesher 1969). The mean activity per gram fresh weight per hour of nitrate reductase was highest at the seedling stage and then declined there after in soybean (Liu and Hadley 1971, Harper and Hageman 1972, Harper *et al*. 1972). The activity of the nitrate reductase enzyme in cotton leaves is dependent on several variables in the growing conditions, such as light, nutrition, water supply, and plant age (Beevers and Hageman 1969). Effect of NaCl and Na_2SO_4 in pea seedlings on NRA and observed decreased activity of nitrate reductase due to salinity and increased accumulation of initial and final products in the chain of nitrate reduction and disrupted protein synthesis. At iso-osmotic concentrations of the salts, suppressionof enzyme activity was greater with NaCl than Na_2SO_4, and a direct relationship between enzyme activity and protein content was observed (Klyshev *et al*. 1974). Balasubramanian *et al*. (1974) observed a differential response of nitrate reductase activity in crop species. The positive effect of IAA and Ca $(NO_3)_2$ on NRA was due to their possible role in the activation of the inactive nitrate reductase protein and prevention of enzyme degradation by proteolysis. This might also be involved in the enhancement of enzyme synthesis or its maintenance in the active form and thus, has a protective role on nitrate reductase activity (Richard and Stanely 1981). The stimulated NR activity in seed priming treatments compared to control plants might be due to enhanced nitrogen uptake by plants **(** Muthuchelian *et al*. 1994). Nitrate reductase (NR) and nitrite reductase activities were substantially declined in leaves and roots of two soybean genotypes grown under varied amounts of NaCl and Na_2CO_3 salts (0-12 dS m^{-1}). Sodium carbonate proved inhibitory than NaCl to both the enzymes, and further, leaves showed higher levels of nitrate reductase and nitrite reductase activity than roots; however, the salt-induced inhibition was higher in leaves (Khan 1996). Nitrate reductase activity (NRA) decreased under water stress in Gomati cultivar of Japanese mint (*Mentha arvensis*), however, when suckers were soaked in the solution of chlormequat chloride (500 ppm and 1000 ppm) for 24 hr. NR activity increased (Priti *et al*. 2005). Germination enzyme alpha amylase plays an important role in hydrolyzing the endosperm starch into sugars, which provide the energy for the growth of roots and shoots (Kaneko *et al.* 2002). Some enzymes and hormones playa critical role in removing dormancy and germination of seeds. The production of α-amylases in aleurone layers is believed to be essential for seed germination, which is tightly regulated by GAs synthesized in the embryo. On the contrary, ABA blocks the production of α-amylases and suppresses seed germination (Ogawa *et al.* 2003). In primed seeds, the activity of α-amylase at 12 hours after sowing was respectively 2.7 and 2.8 times greater than that in non-primed seeds. Seed priming enhanced K^+ concentration in both seeds and seedlings, leading to improved α-amylase activity **(**Ashraf and Foolad 2005). There were positive correlations between seed K^+ concentration and amylase activity, and the concentration of reducing sugars with amylase activity, seedling dry mass, or number of secondary roots (Farooq *et al*. 2006). Osmohardening with KCl performed better than all other treatments, including the control. Priming improved the K^+ balance that activates α-amylase, a basis for seed invigoration. Amylases play a major role in the breakdown of starch in seeds. Improved amylase activity in the primed seeds has been reported, although the extent of the change was different in seeds subjected to different priming treatments (Farooq *et al*. 2006). Enlarged amylase activity and sugar content were also reported in the treated seeds compared with the control (Basra *et al.* 2005). Increased α-amylase activity resulted in increased contents of total and reducing sugars subjected to priming in marigold (Afzal *et al.* 2009). The beneficial effect of priming has been associated with various biochemical, cellular, and molecular events, including the synthesis of DNA and proteins (Srivastava *et al.* 2010). Metabolic repair processes and the buildup of germination metabolites or osmotic adjustments during priming are due to germination enhancement techniques. Enzymes such as amylase, protease, and lipase play a great role in the initial growth and development of the embryo. Every increase in activity of these enzymes results in faster initial growth of seedlings; therefore, their establishment improvement result in higher yield (Mukhtar *et al*. 2013). Singh *et al*. (1999) reported that osmotic priming with PEG results in higher amylase and dehydrogenase activity and increased germination rate in saline conditions. This improvement is a consequence of physiological changes during the priming process, which affects protein enzyme, DNA, and RNA synthesis and activity (Arjenaki *et al*. 2011). Seed priming of mungbean seeds with inorganic salts like KNO_3, $Mg(NO_3)_2$, and Mg SO_4 was found to significantly increase the activities of nitrate assimilatory enzymes, including nitrate reductase and nitrite reductase in seedlings of Samrat, Sulabh2545, and SML668 varieties (Tiwari *et al.* 2013, Singh and Pal 2024). Priming of moongbean seeds with plant growth regulator GA_3 @100 ppm for 08 hours significantly enhanced the activities of nitrate reductase, nitrite reductase, and alpha amylase in seedlings over unprimed control (Tiwari *et al.* 2015). Mung bean varieties Virat, Samrat and Meha when primed with KNO_3 (0.2%) and GA_3 (100ppm) for 06 hours showed significant improvement in activities of germination enzymes alpha amylase and protease over unprimed control under normal as well as drought conditions but the enhancement in activities were relatively higher with GA_3 priming (Tiwari *et al*. 2019). Pigeon pea varieties Bahar and Malviya-13 when primed with growth regulator GA_3 (100ppm) and in organic salt KNO_3 (0.2%) for 06 hours showed significant increase in activities of nitrate reductase, nitrite reductase and anti-oxidant enzymes including catalase, peroxidase and super oxide dismutase in seedlings over un primed control (Tiwari and Agarwal 2020). Potassium nitrate priming of medicago species enhances the activity of Nitrate reductase, GDH, GS enzymes involved in nitrogen metabolism, and the GOGAT cycle. KNO_3 treatment improved the bioactive compound activities by increasing total phenolic and flavonoid contents and also enhancing the antioxidant and antidiabetic activities (Zrig *et al.* 2022).

REFERENCES

Adnan U, Ali S, Hayat R, Muhammad A and Muhammad JT. 2011. Evaluation of seed priming in mung bean (*Vigna radiata*) for yield, nodulation and biological nitrogen fixation under rain fed conditions. African Journal of Biotechnology **10**(79): 18122-18129.

Afzal I, Ashraf S, Qasim M, Basra SMA and Shahid M. 2009. Does halo priming improve germination and seedling vigor in marigold (*Tagetes* spp.).Seed Science and Technology **37**: 436-445.

Afzal I, Basra SMA and Ahmad N.2011. Hormonal priming induces salt tolerance in wheat through enhanced antioxidant defense system. Cereal Research Communication **39**: 334–342.

Afridi MMRK and Hewitt EJ. 1964. The Inducible formation and stability of nitrate reductase in higher plants.I.effect of nitrate and molybdenum on enzyme activity in cauliflower (*Brassica oleracea* var. botrytis). Journal of Experimental Botany **15**(44): 251-271.

Aldesuquy HS and Ibrahim AHA. 2000. The role of shikimic acid in regulation of growth, transpiration, pigmentation, photosynthetic activity and productivity of *Vignasinensis* plants.: Phyton, Annales Rei Botanicae, Horn **40**: 277-292.

Andredi C and Leon. 2000. Matriconditioning integrated with gibberellic acid to hasten seed germination and improve stand establishment of pepper and tomato. Pesquisa do Estado de Minas Gerais (FEPAMIG) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brasília, DF, Brazil **34**(10): 1953-1958.

Argerich CA and Bradford KJ. 1989. The effects of priming and ageing on seed vigor in tomato. Journal of Experimental Botany **40**: 599-607.

Arjenaki FG, Dehaghi MA and Jabbari R. 2011. Effects of Priming on Seed Germination of Marigold (*Calendula officinalis*). Advances in Environmental Biology **5**(2): 276-280.

Arif M. 2005. Effect of seed priming on emergence, yield and storability of soybean. PhD. Thesis, NWFP Agriculture University, Peshawar.

Ashraf M and Foolad MR. 2005. Pre-sowing seed treatment-A Shotgun approach to Improve Germination, Plant growth, and crop Yield under Saline and Non-Saline Conditions. Advances in Agronomy **88**: 223-276.

Balasubramania V, Rajgopal V and Sinha SK. 1974. Stability of nitrate reductase under moisture and salt stress in some crops. Indian Journal of Genetics and Plant Breeding **34**(4): 1055-1061.

Basara M AS, Ehsanullah EA, Warraich MA and Afzal I.

2003. Effect of storage on growth and yield of primed canola (*Brassica napus*) seeds. International Journal of Agriculture Biology **5**: 117-120.

Basra SMA, Farooq M and R Tabassum. 2005. Physiological and biochemical aspects of seed vigor enhancement treatments in fine 48 December 2005 rice (*Oryza sativa* L.). Seed Science and Technology **33**: 29-33.

Basu RN and Choudhary P. 2005. Partitioning of assimilates in soybean seedlings. Annals of Agricultural Research **11:** 285-288.

Beevers l and Hugeman RH. 1969. Nitrate reductase in higher plants. Annual Review of Plant Physiology **20**: 495-522.

Bose B and Mishra T. 1999. Influence of pre-sowing soaking treatment in *Brassica juncea* seeds with Mg salt on growth, nitrate reductase activity, total protein content and yield responses. Physiology and Molecular Biology of Plant **5:** 83-88

Bose B and Mishra T. 2001. Effect of seed treatment with magnesium salts on growth and chemical attributes of mustard. Indian Journal of Plant Physiology **6:** 431-434.

Bose Bandana and Pandey MK. 2003. Effect of nitrate pre soaking of okra (*Abelmoschus esculentus* L.) seeds on growth and nitrate assimilation of seedlings. Physiology and Molecular Biology of Plant **9:** 287.

Braccini AL and Magurie JD. 1998. Speed of germination-aid in selection and elevation for seedling emergence and vigor. Crop Science **2:**176-177.

Christiansen MN and Foy CD. 1979. Fate and function of calcium in tissue. Communication on Soil Science and Plant Analysis **10**: 427-442.

Dharamlingam C and Basu RN. 1993. Invigoration treatments for increase production in carried-over seeds of mung bean. Seeds and Farms **15**(8): 33-34.

Earlpuls EJR and Lambeth VN. 1974. Chemical stimulation of germination rate in aged tomato seeds. Journal of American Society of Horticulture Science **99**(1): 9-12.

Farooq M, Basra SMA, Khalid M, Tabassum R and Mahmood T. 2006. Nutrient homeostasis, metabolism of reserves and seedling vigor as affected by seed priming in coarse rice. Canadian Journal of Botany **84**(8): 1196-1202.

Feng Z, Bo, P and Donald LS. 1997. Application of gibberellic acid to the surface of soybean seed (*Glycine max* (L.) Merr.) and symbiotic nodulation, plant development, final grain and protein yield under short season conditions. Journal of Plant and Soil Science **188**(2): 329-335.

Garai U and Patra S. 2024. Review of the effects of seed priming for improving seed germination, seedling establishment and yield on several pulse crops. Journal of Stress Physiology and Biochemistry **20**(2): 63-79.

Hageman RH and Flesher donna. 1969. Nitrate reductase activity in corn seedling as affected by light and nitrate content in nutrient media. Plant Physiology **35:** 700-708.

Harris D, Pathan AK, Gothkar P, Joshi A, Chivasa W and Nyamudeza P. 2001. Onfarm seed priming: using participatory methods to review and refine a key technology. Agriculture Systems **69:** 151-164.

Harris D, Rashid A, Miraj G, Arif M and Shah H. 2007. 'On-farm' seed priming with zinc sulphate solution-A cost-effective way to increase the maize yields of resource poor farmers. Field Crops Research **102:** 119-127.

Harris D, Tripathi RS and Joshi A. 2002. 'On-farm' seed priming to improve crop establishment and yield in dry direct-seeded rice, in IRRI: International Workshop on Dry-seeded Rice Technology; held in Bangkok, 25-28 January 2008. The International Rice Research Institute, Manila, the Philippines, Pp. 164.

Harper JE and Hageman RH. 1972. Canopy and seasonal profiles of nitrate reductase in soybean. Plant Physiology **49**: 146-154.

Harper JE, Nicholas JC and Hageman H. 1972. Seasonal and canopy variation in nitrate reductase activity of soybean varieties. Crop Science **12**: 382-386.

Heydecker W. 1973. Commercial exploitation of colouring, filmcoating, pelleting and seed invigoration technologies in high value crops seeds by K. Vanangamudi and A. Bharti In: G. Kalloo, S.K. Jain, AliceK. Vari and Umesh Srivastava (Eds) Seeds-A global perspective, ISST New Delhi 2006 PP194-212.

Hocart C, Lethem HDS and Parker CW. 1990. Metabolism and translocation of exogenous zeatin riboside in germinating seeds and seedlings of *Zea mays*. Journal of Experimental Botany **41:** 1517–1524.

Irfan A, Nazir M, Ferhat MAH and Saadia, IGA. 2004**.** Enhancement of germination and emergence of canola seeds by different priming techniques. Bioline International **16:** 19-34.

Kaneko M, Itoh H, Ueguchi-Tanaka M, Ashikari M and Matsuoka M. 2002. The a-amylase Induction in Endosperm during Rice Seed Germination Is Caused by Gibberellin Synthesized in Epithelium. Plant Physiology **168**: 1264-1270

Klyshev LK, Kasisheva TL and Rakova HH. 1974. Effect of sodium salts and different nitrogen forms on nitrate reductase activity and protein synthesis in pea plants. ReferatynauchnykhSoobschenii Tum-1 Riga.Latrian, 133.

Karimi M and Varyani M. 2016. Role of priming technique in germination parameters of calendula (*calendula officinalis* l.) seeds, Journal of Agricultural Sciences **61**(3): 215-226

Khan MG. 1996**.** Nitrate and nitrite reductase activities in soybean plants raised with saline water. Indian

Journal of Plant Physiology **1**(2): 128-129.

Kumar R, Tyagi CS and Ram C. 2002. Association of laboratory seed parameters with field performance in mung bean.Seeds and Farms **15:** 33-36.

Liu MC and Hadley HH. 1971. Relationship of nitrate reductase activity to protein content in related nodulating and nonnodulating soybeans. Crop Science **11**:476-471.

Mc Donald Miller B. 2000. Principles of Seed Science and Technology (4th Ed). Publisher-Springer. Pp 277.

Massawe FJ, Collisions ST, Roberts JA and Azam-Ali SN. 1999. Effect of presowing hydration on germination, emergence and early seedling growth of bambara groundnut. Seed Science and Technology **27:** 893-905.

Maske VG, Dotale RD, Sorte PN, Tale BD and Chore CN. 1997. Germination, root and shoot studies in soybean as influenced by GA3 and NAA. Journal of Soils and Crops **7:** 147-149.

Mishra SN, Chaurasia AK, Bineeta MB and Kumar A. 2017. Assessment of different priming methods for seed quality parameters in pigeonpea (*Cajanus cajan* L.) seeds. Journal of Pharmacognosy and Phytochemistry **6**(3): 522-526

Monalisa SP, Beura JK, Tarai RK and Naik M. 2017. Seed quality enhancement through bio priming in common bean (*Phaseolus vulgaris*. L). Journal of Applied and Natural Science **9**(3): 1740 - 1743

Murungu FS, Chiduza C, Nyamugafata PLJ, Clark WR and Whalley EFS. 2004. Effects of 'on-farm seed priming' on consecutive daily sowing occasions on the emergence and growth of maize in semi-arid Zimbabwe. Field Crops Research **89:** 49-57.

Mukhtar K, Afzal I, Qasim M, Maqsood S, Basra A and Shahid M. 2013. Does priming promote germination and early stand establishment of french marigold (*Tagetes patula* L.) seeds by inducing physiological and biochemical changes? ActaScientiarumPolonorumHortorumCultus **12**(3): 13-21

Muthuchelian K, Murugan C, Hari GR, Nedunchezhian N and Kulandaivelu G. 1994. Effect of triacontanol in flooded (*Erythrina variegate*) seedlings on changes in $^{14}CO_2$ fixation, ribulose 1, 5-biphosphate carboxylase, photosystem and nitrate reductase activities. Photosynthetica **30**: 407-413.

Murungu FS, Zuva E, Madanzi T, Matimati I and Dube ZP. 2005. Seed priming and water potential effects on soybean (*Glycine max* L.) Merr.) Germination and emergence. Journal of New Seeds **7**(17): 57-73.

Musa AM, Johansen C, Kumar J and Harris D. 1999. Response of chickpea to seed priming in the High Barind Tract of Bangladesh. International Chickpea and Pigeon Pea Newsletter **6**: 20-22.

Musa AM, Harris D, Johansen C and Kumar J. 2001. Short duration chickpea to replace fallow after *aman*rice: the role of on-farm seed priming in the High Barind Tract of Bangladesh. Experimental Agriculture **37:** 509–521.

Nalawadi UG, Prithviraj S and Krishnmurthy K. 1973. Improvement in seed germination of soybean varieties by pre-soaking treatments. Indian Journal of Agricultural Sciences **43:** 546-550.

Naphade KT, Sagare BN and Joshi BG. 1996. Effect of seed soaking with chemicals on yield and nutrient uptake by sunflower. Journal of Maharashtra Agricultural University **11**(2): 189-192.

Narayanswamy S and Shambulingappa. 1996. Effect of presowing treatment on seed germination and yield in groundnut. Seed Research **24**(2): 166-168.

Ogawa M, Hanada A, Yamauchi Y, Kuwahara A, Kamiya Y and Yamaguchi S. 2003. Gibberellin biosynthesis and response during Arabidopsis seed germination. The Plant Cell **15:** 1591-1604

Orzesko RA and Podlaski S. 2003. The effect of sugar beet seed treatment on their vigor. Plant Soil Environment **49:** 249–254.

Parera CA and Cantliffe DJ. 1994. Pre-sowing seed priming.Hortculture Reviews **16:**109–141.

Punjabi B, Mandal AK and Basu RN. 1982. Maintenance of vigor, viability and productivity of stored barley seed. Seed Research **10**(1): 69-71.

Priti M, Farooqui AHA and Sharma S. 2005. Ameliorative effect of chlormequat chloride on water stressed cultivars of Japanese mint (*Mentha arvensis*). Indian Journal of Plant Physiology **10**(1): 41-47.

Qingxiang W, Feng Z and Donald LS. 1996, Application of GA3 and Kinetin to improve corn and soybean seedling emergence at low temperature. Environmentol Experimental Botany **36**(4**):** 377-383.

Rama Rao G and Gopel Singh B 1991. Effect of hydration dehydration on growth and yield in soybean. Journal of Oilseeds Research **14**(2): 327-329.

Rao GR and Singh BG. 1997. Effect of hydration-dehydration on growth and yield of soybean. Journal of Oilseed Research **14:** 327-329.

Rashid A D, Harris P, Hollington A and Raffiq M. 2004. Improving the yield of mung bean (*Vigna radiata*) in the North West frontier province of Pakistan using on-farm seed priming. Journal of Experimental Agriculture **40:** 233-244.

Rashid A, Hollington PA, Harris D and Khan P. 2006. On-farm seed priming for barley on normal, saline and saline-sodic soils in North West frontier province of Pakistan using on-farm seed priming. European Journal of Agronomy **24:** 276- 281.

Rangaswamy A, Purushothaman S and Devasenapathy P. 1993. Seed hardening in relation to seedling quality characters of crops. Madras Agriculture of Journal **80:** 535-537.

Richard KN and Stanely K. 1981. Rapid growth and apparent total nitrogen increase in rice and corn plant following applications of triacontanol. Plant Physiology **68**: 1279-1284.

Sashidhar VR, Mekhri AA and Krishina Sastry KS. 1977. Proline accumulation in relation to seed hardening in groundnut genotypes. Indian Journal of Agriculture Sciences **47**(12**):** 595-598.

Singh G, Gill S and Sandhu K. 1999. Improved performance of muskmel on (*Cucumis melo*) seed with osmoconditioning. ActaAgrobotany **52**: 121-126.

Singh G and Pal V. 2024. Agronomic innovations for enhancement of zinc content in pulses: A review. Journal of Food Legumes 37(1): 11-21. https://doi.org/10.59797/jfl.v37.i1.173

Srivastava AK, Lokhande VH, Patade VY, Suprasanna P, Sjahril RD and Stanislaus F. 2010. Comparative evaluation of hydro-, chemo-, and hormonal-priming methods for imparting salt and PEG stress tolerance in Indian mustard (*Brassica juncea* L.). ActaPhysiologiaePlantarum **32**(6):1135-1144

Subbaraman R and Slevaraj JA .1989. Effect of presowing treatment on seed yield and quality in groundnut CV. JL-23. Seeds and Farms **4:** 5-9.

Tiwari TN, Kamal D, Kumar V, Chaturvedi AK and Prasad SR. 2013. Relative efficacy of in organic salts as priming agents on germination, vigor, nitrate assimilation and yield in mungbean. Seed Research **41**(2**)**: 180-189.

Tiwari TN, Kamal D, Singh RK and Prasad SR. 2014. Relative efficacy of seed priming with potassium nitrate and tap water in relation to germination, invigoration, growth, nitrate assimilation and yield of pigeon pea (*Cajanus cajan* L.). Annals of Agriculture Research New series **35**(2):164-170.

Tiwari TN, Kamal D, Singh RK and Prasad SR. 2015. Plant growth regulators priming enhances seed quality andenzyme activity in mung bean (*Vigna radiata* L.). Annals of Agriculture Research New Series **36**(4): 1-8.

Tiwari TN, Prasad SR and Agarwal DK. 2019. Seed priming improves crop growth and yield performance of Pigeon pea (*cajanus cajan* L). Journal of Food Legumes **32**(1): 9-12,

Tiwari TN, Patel SK, Maurya DP and Katiyar PK. 2019. Efficacy of various priming treatments on seed quality, germination enzymes and growth of mung bean cultivars under normal and deficit moisture conditions. Journal of Food Legumes **32**(4**):** 231-235.

Tiwari TN and Agarwal DK. 2020. Seed priming influences the seed quality and activities of nitrate assimilation and Anti-oxidant enzymes in pigeon pea seedlings. Legume Research **10.**18805/LR-4236:1-9.

Tiwari TN and Katiyar PK. 2021. Seed osmo priming in chickpea enhances seed quality and crop performance under normal and water deficit conditions. Legume Research **10**.18805/LR-4544:1-8.

Tiwari TN and Agarwal DK. 2021. The effect of seed priming in chickpea under sodic soil . Journal of Food Legumes **34**(2): 99-104.

Verma SS, Punia RC and Dahiya OS. 2006. Pre-sowing seed treatment for better crop establishment in mung bean. National Seed Seminar, Abstract XII, ANGRAU, Hyderabad, p.145.

Yogananda DK, Vyakarnahal BS and Shekhargouda M. 2004. Effect of seed invigoration with growth regulations and micronutrients on germination and seedling vigor of bell pepper cv. California Wonder. Karnataka Journal of Agricultural Sciences **17**(4): 811-813.

Zrig A, Saleh A, Hamouda F, Okla MK, Qahtani Al, Alwasel WH, Hashmi-YA, Ali A, Egab MY, Hassan AHA and Elgawad-AbdH. 2022. Impact of sprouting under potassium Nitrate priming on Nitrogen assimilation and Bioactivity of Three *Medicago* species. Plants **11**(1): 71. https:. //doi.org/10.3390/plants11010071.