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SEED TREATMENTS-IMPACT ON COTTON SEED QUALITY AND PRODUCTIVITY

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ABSTRACT

Seed treatment is the application of certain curative agents for the enhancement of seed quality, applied through physical means, or chemical, or biological agents to the seed before sowing to suppress, control, or ward off the pathogens, insects and other pests that attack seeds, seedlings, or plants and it ranges from a basic dressing to coating and pelleting. Among the different seed treatments, biological seed treatments are expected to be one of the fastest-growing seed treatment sectors shortly due to its eco-friendliness. Lack of awareness of seed treatments at farmer's level is one of the limiting factors and hence, efforts should be made at farmer's level to adopt the technology. The different seed treatment technologies with their improvement and significance are discussed in this review.

Keywords: Seed treatment, Seed coating, Seed priming, Seed pelleting, Cotton seed

INTRODUCTION

Seed is botanically defined as a matured ovule containing an embryo in an arrested state of development with food reserved in endosperm/ cotyledons surrounded by seed coat which is the protective layer. Seed is the most significant aspect of all agricultural inputs, for two main reasons, first one being the propagule carrying inimitable genetics that culminates in optimum crop response to varying environments. Secondly, it is the reproductive unit responsible for ensuring successful stand establishment for most crops (McDonald, 2003). Many factors can narrow down the gap between potential and farm-level yield. Among them, the use of quality seed is the most important one (Ahmad, 2001) as quality seeds ensures better germination,

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seedling vigour, pest and disease resistance and as well as better yield. In the event of usage of inferior quality planting seed, crop failure is unavoidable. To the farmers for satisfactory crop production, a high-quality seed is not only desirable but also satisfactorily required. Low productivity could be attributed broadly to use of poor quality seeds, soil moisture stress, low and erratic rainfall and improper crop management. To overcome these, new seed management technologies have been developed. The quality of seed is governed by genetic make-up, commonly the quality of seeds may deteriorate in subsequent stages like stage of harvesting, threshing, processing, and storage period. Retention of seed viability and vigour, always forms an important consideration in agricultural practices. The poor seed-handling condition gives rise to deterioration of seed quality and the resultant loss of viability. This also, greatly affects seed vigor, as a result, the quality of the seed becomes poor and the seed is unusable for planting and crop production.

Seed is a biological entity and forthwith deterioration is inevitable after harvest. The cotton seeds deteriorate at a rate sufficiently rapid to make them a poor planting material soon after the attainment of physiological maturity. Consequences of poor quality seeds are poor germination, slow emergence, weak growth, and inadequate field stand etc., all orienting towards reduced yield. Lipid peroxidation and free radical production are believed to be the basic causes for seed deterioration. Unsaturation of free fatty acid components of lipoprotein membranes render them susceptible to peroxidative changes. Therefore stabilization of the same by chemical reduces peroxidation and free radical reactions. To overcome germination and vigour constraints, by uniform crop stands, earlier crop development, and better yields seed treatments through physical, chemical, and biological means have been proposed.

MODE OF ACTION OF SEED TREATMENTS

Seed treatments can be classified as physical, chemical, and biological. Regardless of types, successful seed treatment practices must satisfy the following biological requirements. A good seed treatment would be consistently effective in all conditions, safe during handling and planting of materials, wide safety margin between diseases harmful to the pathogen and that to plants, safe to wildlife, companionable with other materials used on seeds, no harmful residues on plant or soil should be produced. The principles and effectiveness of these various methods are discussed.

TYPES OF SEED TREATMENTS

Different seed treatments are used alone or in combination to address or to prevent several pests, diseases, and nutrient deficiencies and to enhance plant growth. These include physical, chemical, biological, botanicals, individually or in combination thereof. The different methods of

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administration of chemicals and biological materials as seed treatments are through dry dressing, wet application, seed priming, seed pelleting, and seed coatings.

Physical seed treatments

Physical treatments are the external application for the eradication of seed infections by fungi and bacteria, without any hydration or application of chemical materials to the seeds. The main idea is relay up on the enhancement of germination and seedling vigor and crop establishment. Physical treatments consist of heat treatments given to seeds, the most common being hot water, hot air, and electron treatments. Physical treatments are usually done by applying heat to the seeds to contain seed-borne pathogen but to cause minimal damage to the seed tissues. Among these physical treatments, hot water treatment is a long-known technique, by immersion of plant material in agitated water at a predetermined temperature and time. In the past, hot water treatment was regularly used for the sanitization of contaminated cereal seeds (Gilbert *et al.* 2005). Hot water treatment has been used since 1920, before the advent of systemic fungicides (1960), was the only treatment available to eradicate deep-seated infections of seeds. This hot water treatment is still being exploited in cotton for the eradication of internal infection by *Xanthomonas campestris* pv. malvacearum (Honervogt and Lehmann-Danziger, 1992). Despite the conventional seed treatments, radiation treatment has been used for seed germination without affecting the seed structural integrity and collateral DNA damage. Younis *et al.* (1962) has reported that X-radiation doses of 500 r that caused the highest stimulation about boll setting and yield in cotton. It was experimented in upland cotton (*Gossypium hirsutum* L.) and observed that pre-sowing seed heat stress at 60°C for 8 h successfully enhanced the seed vigor thereby increasing the seedling vigor (Basra,2004). The biological effects of radiations are the chemical interaction with biomolecules and water to form free radicals that can manipulate biomolecules and induce the cell to switch on the antioxidant system for a defensive shield against upcoming stresses. Thermotherapy inactivates or kills the pathogen without affecting the host tissue. The study of Krzyzanowski and Delouche (2011) revealed the effect of 10 to 40ºC temperature treatment on the germination rate and germination (%) of two cotton seed lots using a thermo gradient plate. The germination of medium quality cottonseed was consistently higher than for high-quality seed, especially at 38 ºC. Seed treatments with carefully regulated aerated steam at a correct intensity make it possible to kill the pathogens without harming the seeds. In the process of electron seed treatment, electrons act within milliseconds on the surface of the seed coat, destroying the DNA of harmful organisms and keeping intactness of the interior part of seed. In recent years, numerous studies have been carried out to determine whether these treatments can be used to eradicate pathogens.

Chemical seed treatments

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An array of chemicals has been suggested from time to time to contain seed born pathogens. On this score, Shtienberg (1991) evaluated the effects of seed treatment with the systemic fungicides on *Altenaria macrospora* in Pima cotton under glasshouse conditions and the field. Rathinavel and Dharmalingam (2001) studied the cotton seedling vigor in terms of field emergence of fresh as well as halogen treated stored seed lots of 18 genotypes, and found improvement in root length, shoot length, and dry matter production of seedlings that emerged in the field due to halogen treatment. The storability of halogen treated and untreated seeds of cotton genotypes assessed through a rapid deteriorative process (accelerated aging) revealed the positive effect of seed treatment in prolonging shelf life. Kaddi *et al.*, (2002) conducted a study for storage behavior among two varieties of cotton using twenty-five different seed treatment and found that Royalflo @ 5ml/kg and Thiram @ 2gm/kg + Imidacloprid @ 7.5ml/kg maintained significantly higher first count, germination (%), vigor index I and vigor index II as compared to control after 6 months of storage.

Cotton seeds treated with thiamethoxam improved the physiological quality of the seeds and the dosages of 5.0 to 7.0 ml of the Cruiser® 350 FS/kg of seeds were more efficient in improving the physiological performance of cotton seeds (Regina *et al*., 2010). The treatment of cotton seeds with imidacloprid and thiamethoxam were effective against *B. tabaci* for up to 45 days under laboratory and greenhouse conditions and up to ∼2 months under field conditions (Zhang *et al*. 2011). Vardhini *et al.* (2012) carried out a study on the effectiveness of imidachloprid, carbosulfan and thiamethoxam on sucking pest complex of cotton and the effect of vigor and viability of the treated cotton seed, immediately 3, 6, 9, 12 and 24 months after seed treatment. Seed treatment with Thiamethoxam @ 3 and 5g a.i. and imidacloprid @ 5g a.i./kg was effective for four weeks against the sucking pest complex and the period of storage did not affect the performance of the seed dressing chemicals. Chitarra *et al*. (2009) studied the effect of different fungicides for the control of damping-off pathogens. The most efficient treatment in the control of post-emergence damping-off in substrates containing *Rhizoctonia solani*, was obtained with the mixture of tolylfluanid + pencycuron + triadimenol, followed by carboxin + thiram. Davis *et al*. (2012) examined the importance of fungicide seed treatments on cotton using a series of standardized fungicide and found that seed treatments with metalaxyl and penta chloro nitro benzene (PCNB) increased plant stand compared to non-treated seeds.

Biological control agents

The seed treatment with bacterial strains of *Rhizobacteria* is effective in suppressing disease infection by a mechanism called 'induced systemic resistance' in varied crops. Among various bacterial genera, *Bacillus* and *Pseudomonas* spp. are abundant rhizosphere inhabitant bacteria that are the most studied biopriming agents reported to be disease suppressing in plants. Priming

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seeds of many crops with biological control agents (BCA), *Bacillus subtillus* and *Pseudomonas fluorescens* are the most effective approach for controlling seed and root rot pathogens and as a substitute for chemical fungicides without any risk to human, animal and the environment.

Biological seed treatments are microorganisms that will protect the seed and seedlings from plant pathogens. Zhang *et al*. (1996) had shown that treating of cotton seeds with G4 and G6 strains of *Gliocladium virens a*nd the GB03 and GB07 strains of *Bacillus subtilis* suppress the incidence of *Fusarium* wilt of cotton in soil infested with *Fusarium oxysporum*f.sp. vasinfectum and *Meloidogyne incognita* under greenhouse conditions.

Howell *et al*. (1997) conducted a study to assess the bio control efficacy of the fungus *Trichoderma virens* in combination with fungicides against cotton (*Gossypium hirsutum*) seedling disease in the field under different soil and environmental conditions. The treatment of cotton seed with *T. virens* plus metalaxyl generally resulted in greater seedling stands than those in untreated controls and equal to those of the fungicide control. Zaki *et al.* (1998) also conducted a study for the control of cotton seedling damping-off using Burkholderia (*Pseudomonas cepacia)*.

Yao *et al*. (2006) assessed the effectiveness of FZB 24® *Bacillus subtilis* (ABiTEP GmbH Berlin) as a biofertilizer for increasing the cotton yield in comparison with the conventional fertilizer containing NPK. The FZB 24 *Bacillus subtilis*, helps to improve plant growth and yield based on increasing the capacity of roots to mobilize and take up nutrients and substances for overall reproductive plant fitness.

Salah Eddin (2007) experimented with the biological control of bacterial blight of cotton caused by *Xanthomonas axonopodis* Pv. malvacearum with *Pseudomonas fluorescens*. Seed treatment along with the foliar application of *Pf1*significantly reduced the incidence of bacterial blight and recorded the percent disease index of 14.5 as against 43.8 in control. Peroxidase (PO) isozyme analysis also indicated that the application of *P.fluorescens* MMP and *Pf1* and inoculation with *Xam* resulted in the induction of a new peroxidase (PO_5).

Gawade (2009) studied the efficacy of bioagents *i.e*. talc powder formulations of *Pseudomonas fluorescens* (0.6%), *Trichoderma viride* (0.6%), *Pseudomonas fluorescens* + *Trichoderma viride* (0.6%) each and Thiram + carbendazim (0.2%) on seed mycoflora, seed germination, seedling vigour index and field emergence in desi cotton *(Gossypium arboreum* L.). The seed treatment of *P. fluorescens* + *T. viride* was effective in reducing seed mycoflora *i.e. Fusarium oxysporum*, *Fusarium moniliforme*, *Aspergillus niger*, *Aspergillus flams* and *Alternaria macrospora* by 87, 100, 79, 76 and 100 percent respectively over untreated control. The seed

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germination, seedling vigour index, and field emergence of desi cotton was increased by 19.25, 21.33, and 11.27 percent respectively.

Bhattiprolu (2010) did experiment to find out the efficacy of *Pseudomonas fluorescens* against foliar diseases of cotton (*Gossypium hirsutum* L.). Seed treatment with *P. fluorescens*, *Pf*1, followed by 0.2% foliar spray of the same at 10 days interval starting from 30 days after sowing is cost-effective in managing important foliar diseases, *viz* bacterial blight and leaf spots caused by Alternaria, Helminthosporium and Myrothecium. Erdogan and Benlioglu (2010) opined that seed treatment of cotton plants with *Pseudomonas* spp. strains and the known strain *Serratia plymuthica* can help in the biocontrol of *Verticillium dahliae* and improve growth parameters in cotton fields.

Jayakumar and Ramakrishnan (2011) evaluated the application of bio control agents, *Pseudomonas fluorescens*, *Trichoderma viride* and *Paecilomyce slilacinus* against reniform nematode, *Rotylenchulus reniformis* revealed that the combined application of *P.fluorescens* (PF1 strain) as seed treatment @10g/kg of seed (6 x 108 cfu/g) + soil application in split doses @ 1, 0.5 and 0.75 kg/ha at sowing, 30 and 60 days after sowing, respectively, were the most effective method in checking the reniform nematode.

Naraghi *et al.* (2012) conducted a study on two major crops, cotton, and potato to evaluate their growth promotion by the antagonistic fungus *Talaromyces flavus* against the wilt diseases on these plants. The isolate, TF-Co-M-23 was the most effective isolate for cotton plants which increased root length, plant height, plant fresh weight, and plant dry weight by 1.80, 2.26, 1.23, and 1.19 fold respectively.

Bacillus spp. have proven to be suitable for developing stable and efficient biological products because of their ability to produce heat-resistant endospores (Errington, 2003; Yanez-Mendizabal *et al.*, 2012) which survive the stresses of commercial seed treatment better than nonspore-forming species such as *Pseudomonas spp. Bacillus subtilis* was used extensively as a cottonseed treatment in the USA (Brannen and Kenney, 1997) and is currently marketed as Kodiak (Bayer Crop Science, 2014). The inoculums can be applied as water-based slurry with other registered seed treatment insecticides and fungicides through standard seed treatment equipment. Khiyami *et al.* (2014) studied the management of cotton seedling disease complex using different *Bacillus* strains under greenhouse conditions. The *Bacillus circulans* and *B. coagulans* were the most effective strains in controlling the cotton seedling disease.

Natural products

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Misra and Dixit (1976) stated that crude extract obtained from aerial leaves of *Allium sativum* completely checked the mycelial growth of 18 different fungi due to the antifungal activity. Agakishiev *et al*. (1978) reported that cotton seed germination and seedling growth were inhibited by the extracts from ripe fruits of *Rubia tintorum*. Umarova and Urmanov (1978) stated that soaking of cotton seed in *Nostoc muscorum* suspension increased the seed yield by 400 kg ha^{-1}. Usha Goel and Nathawat (1990) found that leaf leachates of *Prosopis juliflora* and *Prosopis cineraria* were not inhibitory to the germination and seedling growth of *Crotalaria medicognea* and *Indigofera linnaei*. Bhardwaj (1993) reported that seed treatment of *Triticum vulgare*, *Glycine max*, *Brassica campestris* and *Vigna mungo* with leaf leachate of *Robina pseudoacacia* did not affected the germination percentage, but did affect shoot and root growth. Kumar and Mohan (1994) used crude extracts of sea weed *Padina pavonica* and *Ulva lactuca* to study their effect on seed germination and seedling growth in *Cicer arientinum* L. and found that Padina extract promoted maximum seedling growth.

Plants extracts contain natural antimicrobial compounds and these can be used for seed disinfection as alternative to fungicide treatments or in combination with physical treatments (Begum *et al*. 2010).

Ogunwole (2005) had experimented using cow dung and poultry litter as soil amendments and extracts of Garlic and Pepper as insecticides on cotton (*Gossypium hirsutum* L.) production in the Nigerian Savanna. Cotton sprayed with extract of West African black pepper produced significantly higher seed cotton and lint yield than the synthetic insecticide.

The study on the efficacy of neem and pungam based botanical pesticides on sucking pests of cotton, *Insitu* count of leafhopper (*Amrasca devastans*) and aphids (*Aphis gossypii*) were made prior to the pesticide application and on 1st, 3rd and 7th day after application of pesticides. Of the different botanicals used, neem seed kernel extract (5%) was found to be effectively followed by *Pongamia glabra* seed kernel extract (5%), neem oil (3%) and *Pongamia glabra* oil (3%) against the sucking pests (Leaf hopper and Aphids) of cotton. A maximum population reduction was noticed on the 3rd day after treatment (Vinodhini and Malaikozhundan, 2011).

COMBINATION OF CHEMICAL AND BIOLOGICAL TREATMENT

Typically, chemical seed treatments do not offer benefits associated with root development, drought-proofing, or crop yield. Treatment of seed with beneficial micro organisms including fungi and bacteria (species of Trichoderma, Pseudomonas, Bacillus, Rhizobia, etc.,) ameliorates a wide variety of biotic, abiotic, and physiological stresses to seed and seedlings (Mastouri *et al*., 2010). Inoculation of seeds with such biological agents in combination with

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priming potentially able to promote rapid and more uniform seed germination and plant growth (Moeinzadeh *et al*., 2010) and in several cases has been reported to enhance and stabilize the efficacy of biological agents.

Raghavendra *et al*. (2009) evaluated the role of cultivars, physical, chemical, and organic treatments in the management of bacterial blight of cotton. Bactericides, chemicals, and organics were applied. Among the cultivars, JK (42 - 44) was found to be resistant and the cultivar LRA 5166 remained highly pathogenic. Hot water treatment and chemicals reduced the incidence of bacterial blight to a lesser extent and the germination was poor. Organic treatments exhibited better performance in increasing germination and in a reduction of blight disease, which was significantly superior over all other treatments by 72, 67, 66, and 68% respectively.

Murugesan and Kavitha (2009) experimented the performance of *Pseudomonas fluorescens* and neem oil along with eight synthetic insecticides such as acephate 75 SP, carbosulfan 25 DS, carbosulfan 25 EC, dimethoate 30 EC, ethofenprox 10 EC, imidacloprid 17.8 SL, monocrotophos 36 SL, and phosalone 35 EC as seed treatments at 10 ml or gm per kg of seeds against *Amrasca devastans* in cotton. Among this, monocrotophos and *P. fluorescens* were found to be effective in reducing the leaf hopper population by more than 50 per cent. In another on farm trial, imidacloprid was found to be the most effective recording the least mean population of leaf hoppers (0.53 /3 leaves). Imidacloprid and monocrotophos were able to reduce the leafhopper population by 72.54 and 59.59 per cent respectively. Laboratory studies have shown that imidacloprid, monocrotophos and *P. fluorescens* improved germination and increased shoot length.

Faria *et al.* (2003) studied the efficiency of the treatments of cotton seeds with the fungicides and comparing them with *T.harzianum*, in the seed germination and vigour in the promotion of seedling growth. Seeds treated with *T.harzianum*, carbendazin+thiram and carboxin+thiram showed higher germination and emergence and the first two also resulted in more vigorous seedlings. Seeds treated with carboxin+thiram produced smaller seedlings with lower dry matter. Howell (2007) in an experiment to determine the disease control efficacy of various biological/fungicide combination seed treatments, in soil infested with pre and post emergence damping-off pathogens. The pre-emergence phase of cotton seedling disease, incited by *Pythium* spp. and *Rhizopus oryzae* was effectively controlled with biocontrol strains of *Trichoderma virens*. The post-emergence phase of the disease can be successfully controlled with systemic fungicides like Baytan, Chloroneb, Deltacoat AD, Dividend, Flint, Maxim, Nuflow M, Vitavax, or Vitavax-PCNB. Control of both pre and post-emergence cotton seedling diseases will therefore require combination seed treatments of biologicals and chemicals. Rant *et* *al.* (2010) also evaluated the effects of bioagents, botanicals and chemicals against bacterial blight of cotton.

Rathinavel (2014) investigated the influence of storage temperature and seed treatments on viability of cotton cv. LRA 5166, revealed that germination, seedling root and shoot length, dry matter and vigour indices decreased with advancement in storage period. However it was noted less influence in seeds treated with carrier based cultures of *Pseudomonas fluorescence, Trichoderma viride* and carbendazim than untreated seeds at each level of storage temperature. Among seed treatments, *Pseudomonas fluorescence* @ 4g/kg and carbendazim treatment @ 2g/kg maintained significantly high seed viability throughout the storage period. Baniani *et al.* (2016) conducted experiment to study the effect of seeds treatment with fungicides and insecticides on germination and vigour, abnormal root production and protection of cotton seedlings.

S.No.	Seed treatments	Method of application	References
1	Starter fertilizer 5 cm to the side and 5 cm below the seed showed	Starter Fertilizer, with fungicide treatments	Stewart and Edmisten (1997)
2	Thiamethoxam and imidacloprid	Systemic insecticide treatment	Zhang *et al.* (2011).
3	*Pseudomonas fluorescens* and neem oil along with Acephate 75 SP, (10 ml or gm per kg)	Combination with synthetic insecticide treatment	Murugesan and Kavitha (2009)
4	*Pseudomonas fluorescens* and neem oil along with carbosulfan 25 DS, (10 ml or gm per kg)	Combination with synthetic insecticide treatment	Murugesan and Kavitha (2009)
5	*Pseudomonas fluorescens* and neem oil along with carbosulfan 25 EC, (10 ml or gm per kg)	Combination with synthetic insecticide treatment	Murugesan and Kavitha (2009)
6	*Pseudomonas fluorescens* and neem oil along with dimethoate 30 EC, (10 ml or gm per kg)	Combination with synthetic insecticide treatment	Murugesan and Kavitha (2009)
7	*Pseudomonas fluorescens* and neem oil along with ethofenprox 10 EC, (10 ml or gm per kg)	Combination with synthetic insecticide treatment	Murugesan and Kavitha (2009)
8	*Pseudomonas fluorescens* and neem oil along with imidacloprid 17.8 SL, (10 ml or gm per kg)	Combination with synthetic insecticide treatment	Murugesan and Kavitha (2009)

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9	*Pseudomonas fluorescens* and neem oil long with monocrotophos 36 SL, (10 ml or gm per kg)	Combination with synthetic insecticide treatment	Murugesan and Kavitha (2009)
10	*Pseudomonas fluorescens* and neem oil along with phosalone 35 EC, (10 ml or gm per kg)	Combination with synthetic insecticide treatment	Murugesan and Kavitha (2009)

METHOD OF APPLICATION OF SEED TREATMENTS

Seed priming

Seed priming is a pre-sowing approach for stimulating pre-germination metabolic activities before the emergence of radicle and improvement in the germination rate and performance of plant growth. It is a controlled hydration process, in which seeds are dipped in water or any solution for a specific period to allow it to complete its metabolic activities before sowing and then re-dried to original weight.

Different priming techniques include osmopriming (polyethylene glycol (PEG) or a salt solution), hydropriming, solid matrix priming (seeds are soaked in the inert medium of known matrix potential) and hormonal priming. For conditioning, a balance of water potential between osmotic medium and seed is necessary, and different non-penetrating agents like organic solutes and salts are used. Furthermore, these seed priming treatments show a positive response only at sub-optimal or supra-optimal field conditions such as drought, excessively high or low temperatures, and salinity.

The effect of hydropriming and osmopriming in mannitol on cotton seed germination during their storage was evaluated by Toselli and Casenave (2014). In the case of hydro priming, the enhancement produced by this priming treatments remained at least for 6 months and 12 months for osmopriming in mannitol. The osmopriming was more effective in increasing the velocity of germination and vigor index. Priming enhanced the behavior in young and older seed lots, however, more effective on the younger seeds.

Murungu *et al*., (2013) carried out a pot experiment with cotton at Zimbabwe. They observed in the laboratory that, priming improved emergence and early growth of cotton in dry soils. The increase of emergence from 75 to 99 % at soil matric potentials and had longer roots than non-primed seedling at all initial matric potentials. There was no direct effect of priming on growth, time to flowering, and maturity or yield of plants. Instead, the advantages of priming appeared to be indirect effects of improvements in crop stand and the advancement of germination and emergence.

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Hydropriming

Hydropriming is a controlled hydration process, which involves soaking of seeds in simple water and then re-drying to their initial moisture. No chemicals are used during this technique, but some cases of uneven hydration cause uneven germination. Hydropriming could be a suitable treatment for under salinity stress and drought-prone environments among the different seed enhancement techniques. It is a risk-free, simple, and cheap technique that has become popular among farmers, with promising effects in the context of an extensive farming system. Hydroprimed seeds produced healthy seedlings, which resulted in uniform crop establishment, drought resistance, early maturity, and also improves yield.

Solid matrix priming

In this method, the seeds are mixed with solid material and water in known proportions. This combination facilitates the uptake of water by the seed to a threshold level. After priming, the solids can be washed away before the seeds are planted. This technique can also be used as a delivery system for chemical and biological control agents (Taylor and Harman 1990).

Osmopriming

The seed hydration in an osmotic solution of low water potentials such as polyethylene glycol or a salt solution under controlled aerated conditions, to permit imbibitions but prevent radical protrusion is called osmopriming. The most commonly used salts for osmopriming are potassium chloride (KCl), potassium nitrate (KNO_3), sodium chloride (NaCl), magnesium sulphate ($MgSO_4$), potassium phosphate (K_3PO_4), calcium chloride ($CaCl_2$) and potassium hydrophosphate (KH_2PO_4). All these salts provide nutrients like nitrogen to the germinating seed, which is required for protein synthesis during the germination process. However, these salts rarely cause nutrient toxicity to the germinating young seedlings. Osmopriming induced more rapid and uniform germination and resulted in decreased mean germination time.

S.No.	Seed treatments	Method of application	References
1	Mepiquat chloride 8 g MC/kg seed	Pre-sowing priming	Yeates (2005)
2	Polyethylene glycol -0.8 MPa	Hydropriming and osmo priming	Toselli and Casenave (2003)
3	H_2O_2 (0.02 and 0.04 M)	Seed soaking or priming	Bordovsky*et al.* (1991)
4	KCl, CCC	Osmo priming	Solaimalai and Subburamu

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			(2004)
5	Potassium Chloride (2%), CCC (500 ppm)	Osmo priming	Thandapani and Subharayalu (1986)
6	Mepiquat Chloride	Hardening	Rethwisch *et al.* (2010)
7	Mepiquat chloride (@ 500 mg kg^{-1})	Hardening	Xu and Taylor (1992)
8	Calcium oxychliride, Calcium carbonate, Iodine vapour(3g/kg)	Dry dressing	Rathinavel and Dharmalingam (2001)
9	$CuSO_4$ and $KMnSO_4$ solution	Seed soaking	Sharaftdinova and Mutalov (1978)
10	$KMnSO_4$ @ 2 g lit^{-1} for 18 h	Seed soaking	Ragah *et al.*(1991)

Hormonal priming

Plant-growth hormones or their derivatives contained by several products are indole-3-butyric acid (IBA), an auxin, and kinetin type of cytokinin. Cytokinins play a vital role in all phases of plant development starting from seed germination up to senescence. Priming with optimum concentration of cytokinins has been reported to increase germination, growth, and yield of many crop species. Gibberellic acid (GA3) is known to break seed dormancy, enhance germination, hypocotyl growth, inter nodal length and cell division in the cambial zone and increase the size of leaves. GA has a stimulatory effect on hydrolytic enzymes, which speed up the germination and promote seedling elongation by degrading the cells surrounding the radicle in cereal seeds.

Various naturally occurring growth-promoting substances such as moringa leaf extract, chitosan, sorghum water extract, and seed weed extract are commonly used for seed priming. Moringa (*Moringa oleifera* L.) as a natural source of plant-growth regulators contains cytokinins as zeatin. Besides, moringa leaf extracts contain higher concentrations of various growth enhancers such as ascorbates, phenolic compounds, K, and Ca. Priming maize seed with moringa leaf extract reduces mean germination (MGT) and T50 with increased germination index and germination count that ultimately improved seedling growth by increasing chlorophyll content, amylase activity and total sugar contents under chilling conditions. Moringa leaf extract diluted up to 1:36 with water was applied on various field crops and a 35% increase in the yield of sugarcane, sorghum, maize, turnip, and bell pepper was observed. Nonetheless, moringa leaf extracts being low cost can be a viable option for improving the productivity of resource-poor farmers.

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S.No.	Seed treatments	Method of application	References
1	IAA (200 ppm) and nutrients $Ca(NO_3)_2$ (3%)	Seed priming	Suresh babu (2006)
2	Ascorbic acid-550 ppm, GA_3 -550 ppm, TIBA -50 ppm	Seed soaking	Sharma *et al.*(1984)
3	GA_3 50 ppm, Succinic acid 0.2%, KH_2PO_4 100 ppm	Seed soaking/Hardening	Rathinavel*et al.*(2004)
4	Cycocel (Chlormequat) at 200 or 400 ppm solution	Seed soaking	Karnail Singh (1976)

Nutrient priming

The application of micronutrients with priming can improve stand establishment, growth, and yield; furthermore, the enrichment of grain with micronutrients is also reported in most cases. Many researchers proved the potential of nutrient priming in improving wheat, rice, and forage legumes. Among micronutrients, Zn, B, Mo, Mn, Cu, and Co is highly used as seed treatments for most of the field crops. Seed treatment with micronutrients is a potentially low-cost way to improve the nutrition of crops. Seed priming with zinc salts is used to increase growth and disease resistance of seedlings.

Seed Hardening

Seed hardening confers high degree of drought resistance; Crafts *et al*. (1949) reported that excessive water loss could be prevented by seed hardening. The physiological induction as a cause of seed conditioning towards increased drought resistance in crops was reported by Henkel (1961). May *et al*. (1962) had enumerated a number of physico chemical changes *viz*., greater hydration of colloids, higher viscosity and elasticity of protoplasm, higher bound water content, increase in temperature, lower water deficit and more efficient root system occurring in plants from seeds given pre-sowing seed hardening treatment. In cotton, Karnail Singh (1976) reported that increased seed yield could be obtained by seed soaking treatment with Cycocel (Chlormequat) at 200 or 400 ppm solution. Sharaftdinova and Mutalov (1978) reported that treatment of cotton seeds in $CuSO_4$ and $KMnSO_4$ solution increased the contents of unsaturated fatty acids, especially linoleic and linolenic acids in chloroplast lipids. Kariev (1981) observed higher 1000 seed weight, seed oil and seed cotton yield in plants from seed soaked in Na salt and δ phenylbutric acid at 0.001 per cent concentrations. Shaban and Eid (1982) reported that soaking cotton seeds in chelated Zn, Cu, Mn, Byfolan (mixed trace elements) 24 h before sowing reduced germination and increased seedling vigour whereas highest germination and seedling vigour was recorded by soaking for 48 h.

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Pothiraj and Sankaran (1984) reported that hardening of cotton seed by soaking in 1000 ppm CCC (Chlormequat) for 6 h followed by drying to the original moisture content before sowing significantly increased the root length; decreased shoot growth and transpiration. The seedlings maintained increased turgidity and showed high water use efficiency. Sharma *et al*. (1984) reported that seed soaking treatment given to cotton with 550 ppm Ascorbic acid or GA_3 or 50 ppm TIBA increased the speed of germination, percentage germination and seedling growth, whereas 2,4, 5-T inhibited the growth. Under drought condition, Thandapani and Subharayalu (1986) recorded higher leaf area, chlorophyll stability index, and relative water content at different growth stages, proline accumulation, dry matter production and seed cotton yield of plants from seed hardened with CCC (Cycocel) at 500 ppm or KCl at 2.0 per cent. On the contrary, Zhang *et al*. (1990) observed reduction in number of nodes, leaves, squares, dry weight of leaves, stems, roots, plant height and total leaf area in cotton due to seed treatment with 0.2, 1.0, or 2.0 g Mepiquat chloride kg^{-1}. Cotton seed soaked in solutions of $KMnSO_4$ @ 2 g lit^{-1} for 18 h increased seed cotton yield (Ragah *et al*., 1991). Soaking cotton seed in solutions of Zn SO_4 @ 2 or 4 g lit^{-1} for 18 h did not affect seed cotton or lint yield (Salwau *et al*., 1991)Xu and Taylor (1992) reported that cotton seed treated with Mepiquat chloride @ 500 mg kg^{-1} of seed gave shorter and more compact shoots without affecting the leaf area and with increased specific leaf weight and chlorophyll content. Agakishiev and Gurbanov (1992) noted increased germination and seedling growth when cotton seeds were soaked in Heteroauxin solution @ 10 or 20 mg lit $^{-1}$.

According to Agakishiev and Bazanova (1992), soaking cotton seeds before germination in Morpholin @ 0.25 per cent increased root length of seedling whereas CCC (Chlormequat) @ 0.1 per cent reduced the root length increased with seed germination. Harb (1992) observed significant increase in seed cotton yield by seed soaking treatment with IAA @ 60 ppm solution. Whereas, significant decrease occurred with Benzyl Adenine for most of growth parameters especially the plant height. Mert (1993) reported that seed germination decreased when cotton seeds were soaked in NaCl solution (conductivity 465 mS/cm) for 24 h and attributed to higher endogenous ABA concentration of about 35 µg/g of fresh weight. Nirmala *et al*. (1994) reported that soaking cotton seed in 2.0 per cent KCl solution for 8 h and drying for 5 h improved the germination percentage.

Seed coating and pelleting

One of the earliest methods of seed "Singulation" was seed pelleting, done to increase the size of the individual seed by coating it with a layer of bentonite clay, pelleting regulates the size of the seed for precision planting.

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Seed film coating, pelleting, priming, and inoculation are globally practiced seed treatments used with the objectives of enhancing plant ability, distribution, germination, and storage of seeds. These techniques aim to apply adhesive films, fungicides, herbicides, growth promoters, and biological agents (Stendahl, 2005). Seed coating is a carrier of chemical materials to support seedling growth (Scott, 1989). Compounds such as growth regulators, inoculants, micronutrients, fungicides, insecticides, and other seed protectants are applied to the pellet to enhance seed performance.

Seed coating demands the uniform application of inert material over the seed surface. This also helps to protect the seed from the soil and seed-borne pathogens (Taylor *et al.*, 1998). The pharmaceutical industry uses seed polymer coating for a constant application of numerous materials to seeds. The commercially available plasticizers, polymers, and colorants (commercially they are readily available to be used as a liquid) are applied as film formulations (Ni, 1997). However, the exact composition of coating material is a carefully guarded secret by the companies who develop them. Usually, coating material contains binders, fillers (e.g., polyvinyl alcohol, gypsum, and clay) and an intermediate layer (e.g., clay, polyvinyl acetate, and vermiculite).

S.No.	Seed treatments	Method of application	References
1	Gypsum (100 g kg^{-1})	Seed pelleting	Rathinavel *et al*. (2000)
2	Micronutrient mixture (Iron 2.0 %, Manganese 4.0 %, Zinc 2.5%, Copper 0.1%, Boron 1.0%,Sulphur 6.0%)15g kg^{-1}	Seed pelleting	Rathinavel *et al*. (1999)
3	Diammonium phosphate (DAP)-40 g kg^{-1}	Seed pelleting	Rathinavel *et al*. (2000)
4	Gypsum, DAP, Micronutrient ($ZnSO_4$ (22.0%), $MnSO_4$ (21.0%), $FeSO_4$ (26.0%) $CuSO_4$ (12.0%) Sodium molybdate (3.0%) and Borax (16.0%))	Seed coating	Saraswathi (1993)

Coating materials

Hanson *et al*. (1961) reported that coating of seed along with chemicals could serve as a protectant against soil organisms, repellent for birds and rodents. According to Patil and Dighe (1983), coating cotton seed with indigenous material such as mud, ash, cow-dung or their combination did not result in better seed germination. Pelleting with mud + cow-dung reduced seed vigour to the maximum. Muruganantham (1996) reported that cotton seeds pelleted with arappu leaf powder recorded more viability and vigour.

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Nutrients

Guttay *et al.* (1957) indicated that the practice of applying small quantity of phosphate salts to the surface of the seed appears to be no different in principle from that of mixing phosphate salt during planting operation. Usonanov *et al.* (1980) reported that cotton seeds pelleted with urea formaldehyde increased germination, maintained plant density and seed cotton yield in saline soil. Cotton seeds pelleted with Gypsum + DAP + Micronutrient recorded higher germination, speed of germination, root length, shoot length and vigour index (Saraswathi, 1993).

Inoculants

Chahal *et al.* (1979) reported that inoculation of Azotobacter chroococcum increased plant height, number of branches, bolls plant-1 and seed cotton yield. Pothiraj (1979) found increased seed cotton yield by application of Azotobacter as seed treatment alone or with FYM. Nehra *et al.* (1990) opined that cotton seed inoculated with Azotobacter replaced 2/3 recommended dose of nitrogen (53 kg N ha-1) and resulted in yield attributes and seed cotton yield at par with recommended dose of nitrogen (80 kg N ha-1). Full dose of nitrogen with seed inoculation of Azotobacter recorded the maximum of 63 per cent of seed cotton yield over control. Jagvir Singh (1994) reported that seed or soil inoculation of Azotobacter increased the nitrogen utilization in cotton there by showing that 15-20 kg nitrogen hectare-1 can be saved. Prasad and Prasad (1994) recorded significant increase in the number of bolls plant-1, boll weight and seed cotton yield by 1.29 tonnes hectare-1 in up land cotton due to seed inoculation with Azotobacter and Azospirillum.

Effect of pelleting on seed quality

Regupathy (1976) observed that coating cotton seeds with aldicarb did not affect germination. Ruban *et al*. (1983) reported that cotton seed coated with Penthiuram and Polymers initially inhibited the activity of catalase and peroxidase and rate of seedling growth but stimulated them later on. According to Patil and Dighe (1983), coating of cotton seeds with indigenous materials such as mud, ash, cowdung and their combination did not result in better seed germination. Balaji (1990) observed that seed pelleting was beneficial for establishing better seed soil contact and thereby enhancing germination, growth and development of soybean and other field crops. Bordovsky *et al.* (1991) reported that upland cotton seeds stored in gel slurry more than 24 h resulted in poor germination whereas; gel slurry containing starch based material improved the germination. Dhindwal *et al.* (1991) noticed no advantage with respect to germination, dry matter of seedling, germination rate and vigour index in undelinted cotton seeds coated with fresh cowdung or ash.

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CONCLUSION

Seed treatments help in increasing the precision and effectiveness of crop protection products by reducing the application rate of pesticides applied to the land area and hence, it is a leading technology in precision and sustainable agriculture. Seed treatments have a wide range of commercial applications from improved crop stands through better germination rates and seedling vigor effective in crop stress management. Among these, biological seed treatments with bacteria and fungi are one of the most appropriate techniques in disease control and growth promotion which can be exploited by the seed industry.

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