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# Seed invigoration: A review

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**Abstract**
Beneficial treatments applied to seeds after harvest but before sowing that increase germination or seedling growth or promote the delivery of seeds and other materials needed at the time of sowing are referred to as seed invigoration. To boost seedling establishment under natural and stressful conditions, many seed invigoration treatments are used in a variety of field crops, including rice. Hydropriming, seed hardening, on-farm priming, osmopriming, osmohardening, humidification, matripriming, priming with plant growth regulators, polyamines, ascorbate, salicylicate, ethanol, osmolytes, coating technologies, and more recently presowing dry heat treatments are some of the treatments used to invigorate rice seed. Seedling establishment is a critical factor that is heavily influenced by seed germination and vigour. Crop priming has the potential to improve the viability and germination of ordinary seeds. It has a remarkable ability to rejuvenate partially aged seeds and boost germination. This technology must be standardised across all crop organisms. Imbibition injury, seed ageing, and their interaction are the major factors affecting seed quality in grain legumes. In vegetable species, seed ageing is a major cause of reduced seed quality. The creation of seed invigoration treatments based on seed hydration has been one approach to their seed improvement. Since seed priming has been proven to be a useful technology, it is necessary to standardise it across all crop species, especially in vegetables and floriculture crops. A thorough examination of current technology and its effects on growth and yield is needed to fully comprehend the seed quality problem.

**Keywords:** Seed invigoration, seed quality, seed priming, seed coating, and germination

## Introduction
Seed deterioration is a major issue in tropical and subtropical countries like India, where high temperatures and humidity hasten the ageing process. Seeds were more susceptible to disease, chromosomal abnormalities, and an increased proportion of morphologically abnormal seedlings as they grew older. They germinated more slowly, breathed slower, and were more susceptible to disease, chromosomal abnormalities, and an increased proportion of morphologically abnormal seedlings as they grew older. All physiological parameters, such as germination percentage, viability percentage, seedling duration, seedling dry weight, vigour index, field emergence index, seedling establishment, and DHA operation, reduced with passage of time (Kumar, 2004 [24] in onion; Desraj, 2002 [7] in coriander and Kumar, 2010 [25] in coriander). The type of seed used has an influence on the seedling establishment of yields (De Figueiredo *et al*., 2003) [13]. Seed invigoration is a term used to describe post-harvest treatments that increase germination or seedling growth, or make seed and other materials easier to deliver at the time of sowing. Priming, hardening, pre-germination, pelleting, encrusting, film coating, and other treatments for seed enhancement are not included, as are treatments for control of seed borne pathogens (Black *et al*., 2006) [11]. 'Priming' is a well-established treatment for enhancing seed quality through the transient activation of the pre-germinative metabolism, which includes antioxidant functions and DNA repair processes (Paparella *et al*., 2015) [38]. Under adverse environmental conditions, seed priming has proven to be an effective method for growing seed vigour and germination synchronisation, as well as seedling growth and field establishment (Ventura *et al*., 2012, Hussain *et al*., 2015) [47]. Hydro priming, osmo conditioning, hormonal priming, and drenching prior to planting are examples of improved seed invigoration strategies that minimise emergence time, achieve uniform emergence, and provide better crop stand in a variety of horticultural crops (Ashraf and Foolad, 2005) [3]. Seed priming has been used as a pre-planting procedure for seed lots that have lost vigour and viability due to poor storage conditions (Pan and Basu, 1985 in carrot and Singh *et al*., 2001 in muskmelon). Seed priming resulted in better establishment and development, prior blooming, increased seed tolerance to antagonistic environment, and a higher yield in maize, according to Harris *et al*., (2007) [21].

The key determinant of seed priming success is proper standardisation of the pre-planting seed treatment technique and strategy for different harvests and cultivars. Farmers' capacity to achieve this goal in the field and in a managed environment/nursery has increased dramatically as a result of seed enhancement by priming (Amin *et al*., 2016) [2]. The aim of priming is to increase the percentage of seeds that germinate. Seedlings from primed seed grow faster, more vigorously, and perform better under adverse conditions (Desai *et al*., 1997) [14].

**Seed quality improvement objectives**

Manipulate seed vigour or physiological status of the seed to improve germination/seedling development.

1. Make seed planting easier (Pelleting, Coating and Encrusting).
2. Deliver the materials needed for sowing (other than pesticides) (e.g., nutrients, inoculants).
3. Using non-traditional seed upgrading methods, remove weak or dead seeds (density, colour and sorting)
4. Seeds are tagged for traceability with visible pigments or other materials/markers.

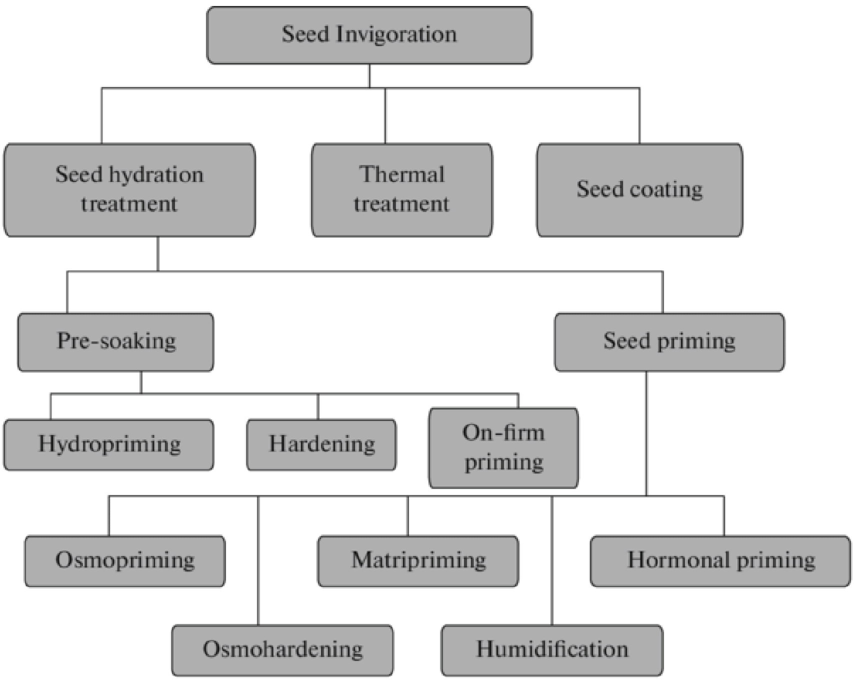
**Invigoration approach**

Seed priming, as first defined by Heydecker *et al*., was the catalyst for the creation of seed invigoration treatments (1973) [24]. Priming aimed to regulate seed hydration such that all seeds germinated at the same time before sowing, resulting in rapid and synchronous germination. This was accomplished by enabling seeds to imbibe from a polyethylene glycol (PEG) solution until the seed water potential equalled that of the PEG solution, which was accomplished at a seed moisture content lower than that needed for germination (radicle protrusion). Before sowing, both seeds had entered the same stage of "suspended animation." Various priming conditions have been used on a variety of organisms, varying PEG concentrations (and therefore water potentials used), temperature, and treatment timing. In a variety of plants, improvements in germination rate and uniformity have been made (Heydecker & Coolbear, 1977) [23].

The theory of regulated hydration in seed invigoration has also been applied to a variety of other procedures, each with its own method of hydration control (Khan, 1992) [2]. Drum priming (Rowse, 1996) [42], solid matrix priming (Taylor *et al*., 1988) [44], hydropriming (van Pijlin *et al*., 1996) [46], and aerated hydration (van Pijlin *et al*., 1996) [46] are examples (Thornton & Powell, 1992) [45]. Seed moisture content is increased by adding a precise volume of water to the seeds in drum priming, while seeds imbibe before their water capacity reaches equilibrium with a moist inert medium or humid atmosphere in solid matrix priming and hydro priming, respectively and requires it takes 14 days' time to complete. Aerated hydration, the final method of seed invigoration to be considered here, was developed at the University of Aberdeen and differs from the others in that it relies solely on time to monitor seed hydration over a treatment period of less than 36 hours.

**Seed Invigoration Strategies**

Seed invigoration techniques are value-added treatments that are applied to a seed lot to help it perform better in the field. Seed priming and this phrase are often used interchangeably. It is, however, an umbrella word that encompasses a variety of presowing techniques. "Post-harvest treatments to increase germination and seedling growth or to promote the delivery of seeds and other materials needed at the time of sowing" are what seed invigoration and seed enhancements are (Taylor *et al*., 1998). This definition (Fig. 1) includes four general methods: hydration therapies in advance (Lee and Kim, 1999, 2000 [31, 32]; Basra *et al*., 2003, 2004, 2005a, 2006b [6, 7, 16]; Farooq *et al*., 2004a; Farooq and Basra, 2005 [6]; Farooq *et al*., 2006b, [16] e, 2007a [17], b, c) Seed treatments with low molecular weight osmo protectants (Taylor *et al*., 1998), coating technologies (Ross *et al*., 2000; Song *et al*., 2005), and, more recently, presowing dry heat treatment have all been investigated (Farooq *et al*., 2004b, 2005b, d).




**Seed Hydration Treatments**

For germination, seed needs water, oxygen, and a warm environment. A triphasic pattern is observed in water uptake (Bewley, 1997) [10]. Imbibition is the first phase, and it begins with the seeds physically taking in water, whether alive or dead. The water potential difference between dry seeds and water is normally very large, so it happens quickly. During this process, there is very little metabolic activity in living seeds. Dead seeds, in reality, can drink water at the same rate as living seeds. The lag time is the second phase. There is little water absorption during this process, so there is little change in fresh weight, but there is a lot of metabolic activity. The seed transforms accumulated reserves (proteins, fats, and lipids) into germination-critical compounds. Radicle protrusion is the third phase. This process is generally associated with the appearance of radicles and is marked by a cycle of rapid water uptake (a rapid increase in fresh weight). During Phases I and II, seeds are desiccation-tolerant, but during Phase III, they often become intolerant. Water the seeds controls each step of water uptake (Taylor *et al*., 1998). Depending on whether water absorption is unregulated or regulated, pre-sowing hydration strategies can be divided into two groups.

**Pre-Soaking**

Pre-soaking refers to methods in which seeds have free access to water and their uptake is not limited by the surrounding atmosphere. The water uptake is regulated by the seed tissues' affinity for water. Imbibing seeds on moistened blotters or soaking seeds in water are two popular methods.

**Hydropriming**

Seeds are soaked in water and dried before sowing in hydropriming (Soon *et al*., 2000) [43]. Soaking can be done with or without aeration by submerging seeds in water (Thornton and Powell, 1992) [45]. Nondormant seeds would germinate quickly if enough water, oxygen, and the right temperature were available. It is an environmentally friendly technique since no chemicals are used during the process. One potential drawback of this method is that seed hydration is often inconsistent, resulting in nonuniform germination (Pill and Necker, 2001) [41]. The time of hydropriming is critical for seed invigoration.

**Hardening**

Hardening, also known as wetting and drying or hydration-dehydration, is the process of repeatedly soaking and drying in water (Pen Aloza and Eira, 1993) [39]. It is possible to repeat the hydration and dehydration cycle twice, three times, or even more times (Lee *et al*., 1998b; Lee and Kim, 2000 [32]). The beneficial effects of seed hardening are primarily linked to embryo pre-enlargement (Austin *et al*., 1969) [4], biochemical changes such as enzyme activation (Lee *et al*., 1998a; Lee and Kim, 2000 [32]; Basra150 M. Farooq *et al*. *et al*., 2005a) [6], and increased germination rate, especially in old seeds (Lee *et al*., 1998a).

**On-farm seed priming**

Faster germination, early emergence, and vigorous seedling growth can result in high-yield crops in a variety of crop species by soaking in water for some time followed by surface drying before sowing, also called as "on-farm priming" (Harris *et al*., 1999, 2000 [35, 22]; Musa *et al*., 1999 [35]). Seed priming on the farm is a quick, low-cost, and low-risk method for encouraging seedling establishment as well as vigorous and faster seedling growth. Soaking time is essential, and it should never exceed the safe limit (time to prime seed) for each crop cultivar. Premature germination will harm seeds or seedlings if the priming period is exceeded (Harris *et al*., 1999) [35].

**Seed Priming**

Heydecker proposed it (1973) [23] Seed priming is a regulated hydration process that is commonly used to improve seed output by improving germination characteristics such as rate and uniformity, as well as lowering seed sensitivity to external factors. Seedlings from primed seed grow faster, grow more aggressively, and perform better in adverse conditions (Desai *et al*., 1997) [14]. After seeds are planted, they must absorb water from the soil for a period of time. By shortening this time, seeds will germinate and emerge more rapidly and uniformly. Seed priming is a strategy for slowing seed adsorption and improving germination and post-dehydration germination. In certain cases, this mechanism aids in the activation of enzymes such as amylases, proteases, and lipases. It increases resistance to drought and heat stress. Priming increases percentage of emergence, rate of emergence, root length, and seed vigour in all Amaranthus varieties (Liu *et al*. 1997). Priming alters the seed's physiological state, which improves germination quality. Water is then removed from the crop, which allows it to be stored before final sowing. During the germination process, treated seeds have a faster and more synchronised germination, and older seedlings have more vigour and are more resistant to abiotic stresses than seedlings from untreated seeds. PEG aids in the reduction of imbibition time, and osmopriming is the process of priming with PEG. Halopriming entails immersion in salts, while hormopriming necessitates the use of plant growth regulators such as gibberellic acid, auxins, and cytokines, among others. Physical factors such as UV, cold, and heat help to control and speed up germination.

**Osmopriming**

It's an osmotic pre-sowing treatment that helps seeds to imbibe water and progress to the first stage of germination while also preventing radicle protrusion through the seed coat (Heydecker *et al*. 1973) [23]. Chemicals such as PEG-6000ppm and potassium dihydrate orthophosphate KH2PO4 are used as an osmotic solution in this priming phase, allowing seeds to easily imbibe water and progress to the first stage of germination while preventing radicle protrusion through the seed coat. Following the seed drying process, this process requires a regulated imbibition process to initiate the first events of seed germination. Osmo-priming has a number of benefits, including faster and more consistent germination and emergence, improved seedling growth, and better stand establishment in any climate or soil (Chiu and Sung 2002 [12]; Nawaz *et al*. 2013 [37]; Singh *et al*. 2015a [38]; Afzal *et al*. 2016 [1]). Osmo-priming seeds with different chemicals increases the rate of germination and promotes the rapid emergence of seedlings in the field (Bose and Mishra, 1992 and Bose, 1997) Osmohardening is a term that refers to the process of hardening 154 M. Farooq *et al*. osmohardening is a modern technique for rice seed invigoration that effectively integrates seed hardening and osmo conditioning (Farooq *et al*., 2006a) [16]. The number and length of cycles are critical in this technique (as they are in hardening) for improving seed vigour. Since this is a new method, it will take a lot of research to find the best salts to use as priming agents for rice seed invigoration. According to the information available, a number of salts were used to osmo harden coarse and fine rice. Both coarse and fine rice seeds were hardened (with water) and osmo hardened (with calcium, potassium, sodium, and potassium nitrate solutions) in a laboratory experiment, with the osmotic potential of all the solutions being –1.25 MPa. Osmohardening for 48 hours with calcium chloride was superior to other treatments for both rice varieties, followed by hardening and osmohardening with potassium chloride.

**Matripriming**

Matripriming entails a regulated seed hydration process that mimics the plant media's natural moisture absorption. Seeds are combined with moist solid carriers like granulated clay or vermiculite (Gray *et al*., 1990 [20]; Hardegree and Emmerich, 1992a, b). These compounds' surfaces produce matrix forces that keep water in place, allowing the seed to absorb it slowly (Taylor *et al*., 1998; Khan, 1992 [2]; Beckman *et al*., 1993). The seed is then removed from the solid carrier and allowed to dry after treatment.

**Hormopriming**

Plant growth hormones such as gibberellic acid, salicylic acid, Abscisic acid, and indole acetic acid are used as priming materials in this process. (Singh *et al*. 2015a [38]; Nawaz *et al*. 2013 [37]). Indole-3-butyric acids (IBA), an auxin and kinetin form of cytokinin, are plant growth hormones or their derivatives found in a variety of items (Afzal *et al*. 2016) [1]. We can enable the formation of enzymes that are required and necessary in the early stages of germination and seedling emergence by thermopriming. Pigeon pea thermopriming: For 6 hours, gibberellic acid (200 ppm) was used. We can induce the relaxation effect in the formation of enzymes by using gibberellic acid (100 ppm) for 12 hours. We can get a better germination percentage, development, and seedling emergence by priming than by sowing normally.

**Humidification**

Humidification is a pre-sowing, regulated hydration treatment in which seeds are equilibrated in high humidity conditions (Perl and Feder, 1981; Finnerty *et al*., 1992) [40, 19]. Seeds are in direct contact with water vapour in this process (Khan, 1992) [2]. Only one research has been conducted to our knowledge to look into the possibility of rice seed invigoration through this method. Humidification of normally germinating rice seeds did not increase germination in favourable conditions, but it did improve germination in unfavourable soil and temperatures (Lee *et al*., 1998a).

**Thermal Treatments**

Seeds are dry-heated for two reasons: to monitor external and internal seed-borne pathogens such as fungi, bacteria, viruses, and nematodes (Nakagawa and Yamaguchi, 1989 [36]; Fourest *et al*., 1990); and to break the dormancy of seeds (Nakagawa and Yamaguchi, 1989) [36]. (Zhang, 1990 [48]; Dadlani and Seshu, 1990). In general, high temperatures minimise seed viability and seedling vigour in dry heat treatments, but the ideal temperature for breaking dormancy promotes rice seed germination and seedling emergence (Lee *et al*., 2002). Dry-heat treatment at 40°C for 72 hours improved germination index, radicle and plumule duration, root length, root/shoot ratio, root fresh and dry weight, radicle and plumule growth rate, and shoot fresh weight in fine rice seeds in a sample. None of these treatments increased seedling vigour or germination in coarse rice (Farooq *et al*., 2004b).

**Seed Coating**

Seeds come in a wide range of sizes, shapes, and colours. Seed size is often small, which makes singularization and precision placement difficult. Seeds should also be protected from a variety of pests that prey on germinating seeds and seedlings. In both cases, seed coating therapies may be used. They can help with mechanical sowing to achieve uniform plant spacing and can be used in target zones with little impact on soil ecology and the climate. Rice seedling emergence was reduced by 40–60% when seeds were coated with a single super phosphate, mono ammonium phosphate, or potassium phosphate, according to Ross *et al*. (2000).

**Physical Methods for Seed Invigoration**:

**1) Magneto-Priming**

An Effective Invigoration Technique The impact of MFs on living organisms have gotten a lot of press. The MF (50 T) of the Earth is a natural component of the climate (Belyavskaya, 2004) [8]. One Tesla (T) unit of magnetic flux density equals 1 kg s-2A-1, where A stands for Ampere, the unit of electrical current or the current flowing with a one Coulomb per second electric charge. For the first time, Krylov and Tarakanova (1960) [28] published on the effects of MFs in plants. When referring to the auxin-like effect exerted by MFs on germinating seeds, they developed a term for magneto tropism. Several reviews published recently summarised the effects of MFs on a variety of biological processes in plants, including growth, development, and metabolism (Maffei, 2014 [33]; Wolff *et al*., 2014). In agriculture, both static magnetic fields (SMF) and electromagnetic fields (EMF) are used for seed priming (also known as "magneto-priming"), and both have been shown to improve seed germination, vigour, and crop yield (Baby *et al*., 2011) [5].

| Species | Magnetic fields (MFs) applied | Effects described | Reference |
|---|---|---|---|
| *Triticum aestivum* | 30 mT | No stimulation of seed germination, neither seedling growth. Increased antioxidant potential under soil flooding. | Balakhnina et al., 2015 |
| *Tagetes patula* | 100 mT | Improved germination, seedling vigor, and starch metabolism. | Afzal et al., 2012 |
| *Glycine max* | 200 and 150 mT | Increased germination parameters and seedling biomass. Plants with higher efficiency of light harvesting and biomass accumulation. | Baby et al., 2011; Shine et al., 2011 |
| *Helianthus annuus* | 50 and 200 mT | Increased germination and germination rate. Increased seedling length and biomass accumulation. | Vashisth and Nagarajan, 2010 |
| *Vigna radiate* | 5 mT | Improved germination, seedling vigor, and starch metabolism. | Reddy et al., 2012 |
| *Solanum lycopersicum* | 100 and 170 mT | Improved biomass and growth. Increased tolerance to biotic stresses. | De Souza et al., 2006 |
| *Cucumis sativus* | 200 mT | Improved germination, seedling vigor, starch, and anti-oxidative metabolism. | Bhardwaj et al., 2012 |
| *Zea mays* | 100 and 200 mT | Improved seedling growth, leaf water status, and photosynthesis in seedlings under soil water stress. | Anand et al., 2012 |
| *Vicia faba* | 0.1 mT | Improved seedling growth. | Rajendra et al., 2005 |
| *Quercus suber* | 0.015 mT | Improved sprouting rate and seedling biomass. | Celestino et al., 2000 |

**Ionizing Radiation Treatments**

Gamma Radiation Is a Potentially Invigorating Treatment

In the field of agricultural sciences and food technology, ionising radiation is an important method that is commonly used to solve food microbiological protection and storability issues (Jayawardena and Peiris, 1988) [25]. Gamma () radiation is a form of infrared radiation with a high energy that can penetrate and interact with living tissues. Cobalt-60 (60C) sources are commonly used to deliver it (Moussa, 2006) [34]. The absorbed dose of IRs is measured in Gray (Gy), with one Gy equalling one Joule of radiation energy absorbed per kilogramme. The absorbed dose of IRs when communicating with biological material (organism, organ, tissue) can also be expressed in Sievert units (Sv), where 1 Sv dose equals 1 Joule radiation energy adsorbed per kilogramme of organ or tissue weight. The dose rate is another important factor to consider when developing IR treatments (rate of energy deposition, expressed as Gy h-1).

**Impact of X-Rays on Germination of seed and Development of seedling**

Till now no one has known the effects of x-rays on living organisms. x-rays have a wavelength in the electromagnetic spectrum ranging from 0.01 to 10 nm, corresponding to frequencies in the range of 30 to 30000 PHz (1 Petahertz equals 1015 Hertz) and energies in the range of 120 eV to 120 keV. Due to their low penetration strength and ability to expose internal density changes, soft X-rays with energies of about 0.12 to 12 keV are the best X-rays to use on agricultural products (Kotwaliwale *et al*., 2014) [27]. Food has been treated with X-rays to increase microbiological protection and shelf life (Farkas and Mohácsi-Farkas, 2011) [15]. Although the effect of X-rays on humans has been well researched due to their widespread use in medical practise, studies on the impact of X-rays on plants only began in the 1930s and 1960s (Benedict and Kersten, 1934 [9]; Bless, 1938; Smith, 1950; Caldecott *et al*., 1952; Yagyu and Morris, 1957; Beard *et al*., 1958)

**Conclusion**

Improved seed invigoration techniques, such as hydro priming, osmo conditioning, hormonal priming, and soaking before sowing, are well known for reducing emergence time, achieving uniform emergence, and providing better crop stand in many horticultural crops. To get the most out of seed, it's critical to choose the right priming period and process. Production of grain legumes may be altered to will the occurrence of cracked Testa. Using different seed invigoration techniques, seeds can be carefully handled and monitored to prevent seed ageing. Seed invigoration treatments can improve seed quality in a variety of crop species. However, in order to ensure consistent growth in seed technology, research on seed invigoration must be enhanced.

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