E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; SP-7(7): 530-536
Received: 02-05-2024
Accepted: 06-06-2024

Ranjeetha R
Department of Horticulture, College of Sericulture, Chintamani, Karnataka, India

Shobha KV
Department of Seed Science and Technology, College of Sericulture, Chintamani, Karnataka, India

Surekha S
Department of Crop Physiology, College of Sericulture, Chintamani, Karnataka, India

Corresponding Author:
Ranjeetha R
Department of Horticulture, College of Sericulture, Chintamani, Karnataka, India

Seed priming: An emerging means for sustainable production of major seed spice crops

Ranjeetha R, Shobha KV and Surekha S

DOI: https://doi.org/10.33545/2618060X.2024.v7.i7Sh.1125

Abstract
Germination and seedling emergence are the critical stages in plant life cycle. Insufficient seedling emergence and inappropriate stand establishment are the main constraints in crop production, thus, a novel technology called seed priming plays a vital role for overcoming these aspects. Seed priming is a pre-sowing seed treatment technique, a pragmatic option to improve seed germination, seedling vigour, crop stand, growth, and yield, quality of horticulture and field crops. It is a controlled hydration technique in which various priming agents such as: water, inorganic salts, osmotic solutions, solid matrices, hormones, bio agents, nutri solutions, nano particles and physical agents are used commercial for enhancing yield and productivity in major seed spice crops. These seed spice crops are potential crops of India, which are commercially cultivated and exported. The priming techniques rely on the controlled uptake of water to achieve a critical moisture content that will activate metabolic activity in a controlled environment. Priming, also called as sensitization or surfacing, is a simple, practical, effective, eco-friendly, and cost-effective approach for improving plant tolerance to various environmental stresses. Thus, it is a widely accepted process that accelerates germination rates, encourages seedling uniformity, enhances cross-tolerance to abiotic stresses thus, contributing to overall productivity of major seed spice crops.

Keywords: Priming, seed spice crops, abiotic stress, germination, productivity

Introduction

A seed is a mature ovule comprises an embryo or undeveloped plant and food reserves, all enclosed within a protective seed coat. Seeds are a way of reproduction for most of the plants. Every seed is capable of growing into a new plant under optimum environmental conditions (right temperature, moisture and sunlight). Seed is a fundamental aspect in crop production; and optimum seed germination is a prime condition for establishment of a crop (Mohammad *et al.*, 2020) [41].

Crop production is a complex attribute extensively dependent on three important factors that is., successful plant establishment, plant stand and high seedling vigour which affects uniform crop growth, maturity and productivity (Christos *et al.*, 2019) [10]. The critical stages during the growth of crop are uniform seed germination, early seedling growth, and uniform plant stand. Low crop yield is attributed to uneven seed germination and seedling growth (Dutta., 2018) [12]. During this era of climate change (Ranjeetha and Raviteja., 2023) [46]., the percentage of seed germination, seedling emergence and seedling vigour is adversely affected. This is due to vagaries of climate, environmental factors and abiotic stress which have resulted in poor crop emergence and yield (Ranjeetha and Raviteja., 2023) [46]. Thus, to enhance seed germination, seed treatment techniques have been adopted (Arunkumar *et al.*, 2019) [5]. Seed priming is one of the seed treatment technique followed commercially in majority of horticulture crops to reduce the time between seed sowing to emergence. The seed priming theory was first reported by Heydecker., 1973 [19].

Seed priming is a process of controlled hydration of seeds (Harmeet *et al.*, 2015) [18], priming allows some of the metabolic processes necessary for germination to occur without allowing the germination to occur (Javid *et al.*, 2013) [23] that is., the pre germination metabolic activities will start but the radicle protrusion is prevented as the seeds will be dried to initial moisture content (Sharma *et al.* 2015) [48]. Seed priming is a pre-sowing treatment which leads to a physiological state that enables seed to germinate more efficiently (Stanley *et al*., 2016) [53]. Priming is one of the important strategy to combat the actual and emerging issues of sustainable crop production in adverse environments by enhancing crop yields through primed seeds due to which the plant will develop tolerance to biotic/abiotic stresses which in turn enhances plant performance (Ibrahim, 2016; Wojtyla *et al*., 2016; Farooq *et al*., 2017) [21, 56, 14]. There are many techniques of seed priming which are broadly divided into conventional methods (hydro-priming, osmo-priming, nutrient priming, bio-priming, solid matrix priming, priming with PGR's and plant extracts) and advanced methods (nano-priming and priming with physical agents) (Stanely *et al*., 2016) [53]. Seed priming is followed in horticultural crops including seed spice crops for enhancing germination percentage, germination index, crop stand, survivability under stress condition (Muhammad *et al*., 2019) [42].

Seed spices are major ingredients in Indian cuisines. India is rightly called "the land of spices" as it is the largest producer, consumer and exporter of spices in the world. The total area under spices in India is about 44.37 lakh hectares with a production of 111.40 lakh metric tonnes and productivity of 2.51 metric tonnes per hectare (Anon., 2023) [3]. There are about 109 spices that are grown in different parts of the world, out of which, 63 spices are grown in India, which includes 20 seed spices. The most prominent seed spices are ajwain, aniseed, caraway, celery, coriander, cumin, dill, fennel, fenugreek and nigella (Arvind *et al*., 2018) [6]. Throughout India, one or the other seed spice is being cultivated, Rajasthan and Gujarat are leading states and hence, they are considered as "seed spice bowl" (Lal., 2018) [29]. Seed spices own a remarkable place in total basket of spices of the country. Since these are important export-oriented agricultural commodities, there is a scope to increase the production of seed spices by introducing them into new and nontraditional areas. Thus, ensuring a seed spice crop stand is an important aspect, which invites seed priming, a technology to meet the crop growth, crop stand, crop survivability, final yield and quality.

Process of seed germination

It is a complex metabolic cum physiological process, involving activation of food reserves, emergence of radicle and plumules (Kamithi *et al*., 2016) [26].

Stages in seed germination (Bareke., 2018) [7] (Fig.1)

1. Primary stage

- Imbibition of water or hydration of seed
- Activation of metabolic process (respiration and protein synthesis)

2. Secondary stage

- Conversion of stored food (starch to sugars in cotyledon or endosperm)
- Translocation of the food to embryo for nourishment and growth

3. Tertiary stage

- Cell division will take place leading to growth and development of seedling.

In case of primed seeds (Fig. 2), the seeds are dried to initial moisture content after seed treatment with priming agents, so that the metabolic processes are completely stopped and seeds can be stored until sowing. Once the seeds are exposed to moisture content, the process of cell division and elongation will succeed and radicle protrusion occurs leading to seedling development.

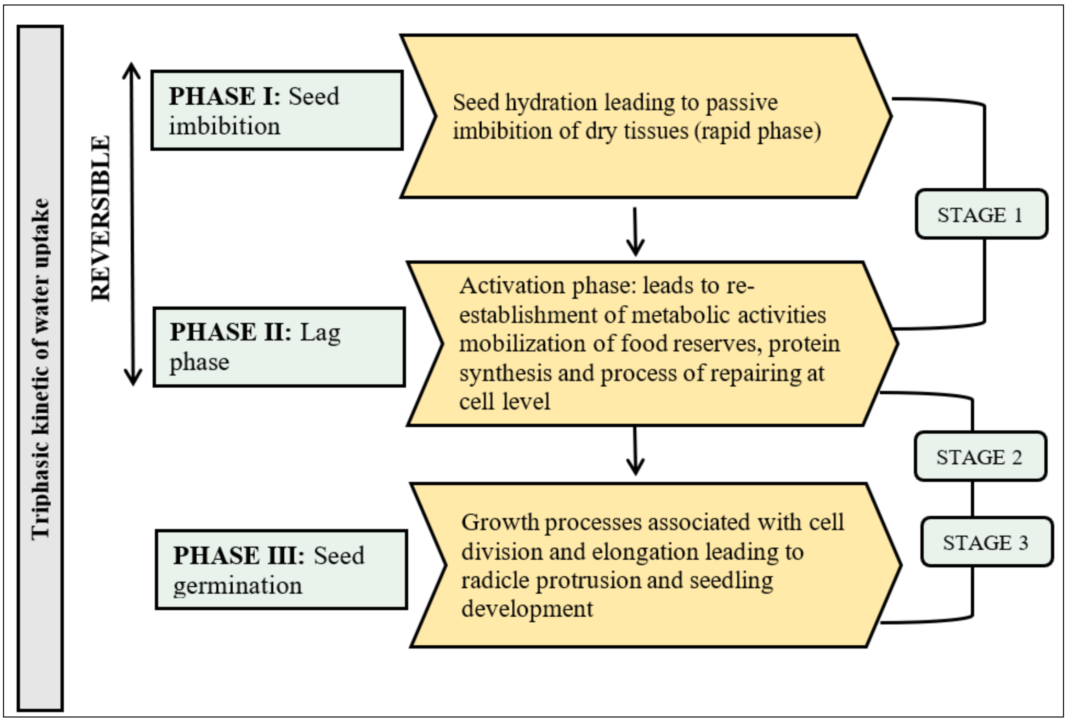

Fig 1: Stages of seed germination in unprimmed seeds

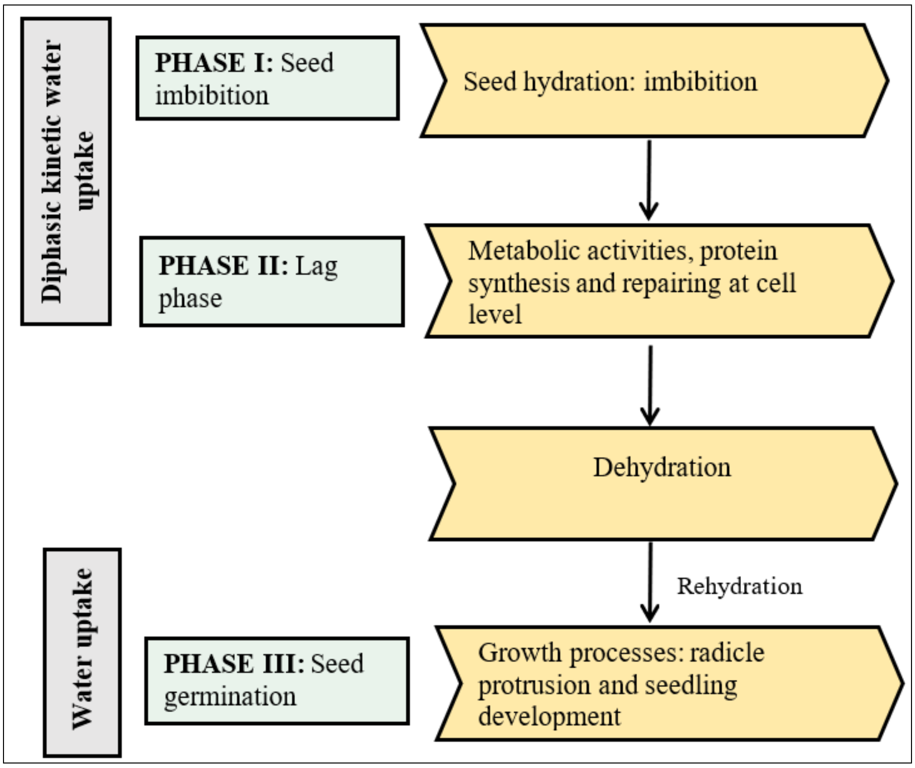

Fig 2: Stages of seed germination in primed seeds

Factors affecting seed germination

1. Internal factors

- **Seed physiology:** some seeds undergo a resting period or dormancy to sustain unfavourable environmental or internal factors if any
- Phyto-hormones
- Hard seed coat
- Immature embryo- the embryo is not fully developed when the seed is dispersed
- Chemical inhibitors

2. External factors: light, temperature, water, nutrients, moisture or mechanical cues

Types of seed priming

Hydro priming: A simplest method of priming seeds, in which seeds are soaked in pure water for a certain period of time at a particular temperature depending on the crop species, the seeds are then dried to initial moisture content (Stanley *et al.*, 2016) [53]. This is a low cost, in other words, an inexpensive technology as no chemicals are used (Mohammad *et al.*, 2024) [40]. The effect of hydro- priming depends on factors such as, the length of exposure to the water followed by dehydration (Dipika and Dhirendra., 2020) [11]. Imbibition of water during hydro priming has resulted in maximum germination percentage (Forti *et al.*, 2020) [15].

Halo priming: Soaking of seeds in solution of inorganic salts: NaCl, $CaCl_2$, KNO_3, $CaSO_4$, KCl, K_3PO_4, KH_2PO_4, $MgSO_4$, is referred as halo priming. Halo priming activates seed metabolism by production of osmolytes or signaling molecules, thus promoting germination (Meenakshi *et al.*, 2019) [35]. A number of studies have shown a significant improvement in seed germination, seedling emergence and establishment, and final crop yield in salt affected soils in response to halo priming (Javid *et al.*, 2013) [23].

Osmo priming: This is also known as osmo-conditioning or osmotic conditioning (Javid *et al.*, 2013) [23]. The process of soaking seeds in aerated osmotic solutions at different concentrations is called osmo priming. Different osmotic solutions such as sugar, polyethylene glycol (PEG), glycerol, sorbitol, and mannitol are used followed by surface drying or redrying to their original weight (Sher *et al.*, 2019) [49]. The water potential of osmotic solutions is lower than pure or distilled water; these solutions permit seed imbibition leading to activation of early phases of germination because of partial seed hydration (Mohammad *et al.*, 2020) [41]. Commonly used priming agent is polyethylene glycol (PEG) due to its larger molecular size, non-toxic nature, and lower potential without penetrating into seeds during soaking (Sher *et al.*, 2019) [49]. Osmopriming of seeds with PEG has great potential to improve stand establishment and performance of crop plants under stressful environment (Zhang *et al*. 2015) [58].

Hormonal priming: The process of priming seeds using hormone solutions is known as hormonal-priming (Javid *et al.*, 2013) [23]. Seed metabolism is directly affected by the plant growth regulators used for hormo priming. Hormones or plant growth regulators such as abscisic acid, salicylic acid, ascorbic acid, cytokinins, auxins, gibberellins, kinetin, ethylene, polyamines are most commonly used for hormonal priming which promote the growth and development of the seedlings (Mohammad *et al.*, 2020) [41].

Solid Matrix priming (SMP): A matri-conditioning is a seed treatment process in which seeds are primed with known proportions of a solid material and water, the seed and matrix used for SMP will compete for available water. SMP utilizes 'solid medium' (matrix which delivers water and nutrients to seed prior to emergence of radical) for seed priming purpose (Sher *et al.*, 2019) [49]. The solid medium will have low bulk density and low osmotic potential and high water-holding capacity. The moistened seeds are mixed with insoluble solid matrix or an organic carrier and their moisture level is maintained to a level just below seed sprouting (Nakkeeran *et al*., 2021) [43]. SMP is accomplished with the controlled and limited hydration, as in hydro priming and osmo priming. The seeds absorbs water will reach an equilibrium point, a precise point for priming to occur. The seeds will be separated from the matrix followed by thorough washing and drying. As a result, an optimally hydrated, metabolically active state can be accomplished within the seed. This include, repair of membranes and/or genetic material, development of immature embryos, alteration of tissues covering the embryo, and removal of dormancy. The solid medium used in the mixture hydrate seeds slowly and simulates the natural imbibition process in the soil (Sher *et al*., 2019) [49].

Bio priming: Bio-priming is an ecological approach which combines biological aspects (seed inoculation) with beneficial organism to protect the seed, control diseases and physiological aspects (hydration of seed). It is a newly emerged technique of seed treatment which integrates the physiological process of seed hydration with biological process of seed inoculation with the beneficial organisms (Rakshit *et al*., 2015) [45]. The procedure of bio priming was first introduced by Callan *et al*. (1990) [9], which has been adopted as an alternate method for managing the soil and seed borne pathogen. This noval seed treatment includes controlled hydration of seeds with beneficial microorganisms and enhancing the preparatory processes prior to germination. Like other seed priming techniques, radical protrusion in not allowed in the bio priming (Sher *et al*., 2019) [49]. Use of beneficial microbes for bio priming offers an innovative crop protection tool as it improves the seed quality, seedling vigor, and plant ability to withstand the suboptimal growth conditions, thus ensuring the sustainable crop production (Rakshit *et al*., 2015) [45]. Bio priming speeds the germination process, ensures the uniformity of seedling emergence, and improves the crop yields and quality (Mahmood *et al*., 2016) [32].

Nutri priming: The priming of seeds in different micro nutrient solutions to improve the micro nutrient availability into plants and their final assimilation in the seed (bio fortification) to reduce the malnutrition. Seed priming with zinc, boron, and magnesium at optimized rates improves the performance of crops owing to an improvement in seed germination, growth, and yield parameters (Sher *et al*., 2019) [49].

Seed priming through Nano particles: Particles of less than 100 nm in size are called nano particles. Nano particles have promising role in transforming food production and agriculture (Fraceto *et al*., 2016) [16]. The mechanism behind high seed germination in nano-priming is the greater penetration via seed coat that improves nutrient and water uptake efficiency of the seed (Dutta., 2018) [12].

Seed priming with physical agents

The application of physical agents such as ionizing and non-ionizing radiations (X-rays, gamma rays; and ultrasonic wave, magnetic field, microwaves, and infrared light, respectively) for seed priming has created a new horizon in the domain of seed technology. Being eco-friendly and cost-effective approaches, priming with physical agents ensures enhanced production over conventional methods (Kuntal *et al*., 2022) [28]. Ionizing radiation (IR) has assured biological advantages over other seed priming methods as it produces charged ions while penetrating through the target organisms, and it has enough energy to cause biological effects (Jiaqi *et al*., 2022) [24].

Seed priming in major seed spice crops

Ajwain: ajwain seeds primed with chitosan solution improves the germination and growth under salt stress condition (Mahdavi and Rahimi., 2013) [30]. Seed priming with 7.5% moringa leaf extract and 200 ppm Gibberellic acid resulted in robust germination of ajwain seeds, accelerated growth and plant development which led to exceptional yield (Manoj *et al*., 2024) [34]. The first combination report with bio priming agents Chitosan + *Pseudomonas fluorescens* + *Pseudomonas aeruginosa* resulted in highest seed germination rate (6.63) followed by combination of Chitosan + *Bacillus megaterium* + *Bacillus subtilis* (6.53) (Mishra *et al*., 2023) [37]. The highest ajwain seed yield of 2510.247 kg/ha was obtained from seed priming with Chitosan + *Trichoderma viride*., similarly, the combination of Chitosan + *Bacillus paramycoides* + *Pseudomonas aeruginosa* resulted in improved final germination, shoot length, root length, plant height, primary and secondary branches, and test weight (Mishra *et al*., 2022) [38]. Ajowan seeds showed minimum germination at an osmotic potential of - 0.2 MPa, beyond this level there was complete inhibition (100%) of germination. Although, the seeds did not germinate at an osmotic potential less than - 0.2 MPa, this might indicate an important survival mechanism that ensures dormancy until sufficient moisture is available for optimal seed germination and seedling establishment (Yogita Rohamare *et al*., 2014) [57].

Aniseed: As per the reports of Batool Mahdavi (2016) [8], priming with 0.05 up to 0.2% chitosan concentrations resulted in production of highest germination and seedling growth. Hence, seed priming with low concentration of chitosan could be used for improving germination and seedlings growth of anise. Sibel Day and Nilufer Kocak-Sahin (2023) [51], reported that anise seed priming with $MgCl_2$ improved seedling growth attributes under greenhouse conditions and highest chlorophyll content was obtained from the seedlings primed with $CaCl_2$ for 4 h. Thus, priming with $MgCl_2$ was significantly promotive and better compared to hydro-priming and osmopriming methods.

Caraway: Osmo priming of caraway seeds (*Carum carvi* L. var. *annua*) with PEG resulted in improved germination, fresh and dry plumule weights in caraway (Mirmazloum *et al*., 2020) [36].

Celery: The research work of Iman *et al*. (2014) [22] for improving the tolerance of celery seeds resulted in alleviating the chilling stress, stimulating celery growth, and proliferation by seed priming with Humic acid and potassium silicate. Further, ionizing radiation at low doses had a stimulative effect on plants after 120 days from planting.

Coriander: Hydro-priming of coriander seeds for 12 hours and priming with GA_3 (50 ppm) and PEG 6000 (-1.1 MPa) for 24 hours were found best treatment for enhancing seed germination and seedling growth traits (Arshia *et al*., 2018) [4]. Combination seed priming with Azatobacter + Phosphate solubilizing bacteria + *Pseudomonas* has resulted in production of highest root and shoot length (3.46 cm & 9.65 cm, respectively), root weight, shoot weight and total biomass (15.02 mg/5 pl, 250.70 mg/5 pl & 265.72 mg/5 pl, respectively) (Warwate *et al*., 2017) [55]. Coriander seed priming with 0.1% of KNO_3, 16 hours of soaking of same coriander seeds resulted in maximum germination percentage (100%), seedling length (21.30 cm), vigour index (2130) and minimum electrical conductivity (1.267 m Scm^{-1}) (Sowjanya and Dutta., 2021) [52]. Maximum germination percentage, mean germination time, shoot length, root length, vigour index-I and vigour index-II was obtained with seed priming with 450 ppm manganese. Seed priming of coriander is found to mitigate crop loss by overcoming poor germination and inappropriate crop stand (Parul *et al*., 2022) [44].

Cumin: Seed priming improved germination, establishment and seedling growth of cumin under drought stress condition (Amirnia and Ghiyasi., 2016) [2]. Cumin seed priming exhibited significantly increased dry matter accumulation and relative growth rate (RGR), further, the concentration of K^+, Ca^{2+} and Mg^{2+} increased significantly and concentration of Na^+ decreased significantly in seedling of primed seeds (1M NaCl). Thus, the use of NaCl as pre-treatments is a useful strategy to increase the salt tolerance of cumin plants in the long-term and to permit the establishment of cumin crop by direct sowing in a saline medium (Mahmood *et al*., 2014) [31]. Cumin seeds of different lifetimes (12 and 24 months old seeds) primed with NaH_2PO_4 and ascorbic acid exhibited improved germination indices compared to hydro priming (Ali *et al*., 2023) [1]. Cumin variety GC-4 primed with PEG (-1.0 MPa) exhibited highest germination percentage (80.81%), the longest root, shoot and seedling length (5.20 cm, 4.61 cm and 9.59 cm, respectively), the highest seedling fresh and dry weight (216.40 mg and 11.81 mg, respectively) (Saxena *et al*., 2015) [47], the highest seedling vigour index-I and II (812.47 and 952.70, respectively) (Hansaliya *et al*., 2022) [17].

Dill: Hydro priming of dill seeds for 27 hr resulted in highest germination percentage (83%), seedling vigour (41.66) and seedling dry weight (0.502 g) (Karimian., 2011) [27]. Mirshekari's (2012) [39] experiment revealed that priming dill seeds with Fe (1.5%) + B (1%) solution produced higher germination percentage (98%), seed yield (855 kg/ha) and essential oil yield (23.43 l/ha).

Fennel: Seed priming with KNO_3 exhibited highest positive effect on germination percentage (84.33%), plant height and number of main branches. Seed priming with KNO_3 (3.06%) and GA_3 (2.93%) resulted in highest positive effect on essential oil percentage (Hossein *et al*., 2013) [20].

Fenugreek: Under undesirable conditions (salinity stress), priming fenugreek seeds with NaCl (4g l^{-1}, 36 h) will initiate suitable metabolic reaction in seeds and improves seed germination (Maher *et al*., 2012) [33]. Priming of 48 hours aged seeds with 2800 µM SA has resulted in increased seedling tissue water percentage (94.48%) (Farahmandfar *et al*., 2013) [13]. The highest seedling length, plumule dry weight and seedling dry weight were observed in seeds treated with 2800 µM SA (Sina *et al*., 2018) [50]. Seed priming with curry leaf extract (3%) exhibited high seed germination percentage (84.00%), germination energy (27%), speed of germination (35.82), root length (6.65 cm), shoot length (5.78 cm), seedling length (10.05 cm), seedling fresh weight (1.90 g) and seedling dry weight (0.04 g), seed vigor index I (844.20) and seed vigor index II (3.94) (Joycy *et al*., 2018) [25].

Nigella: Black cumin seed priming with potassium humate exhibited highest germination index (5.83) and germination rate (93%); seed priming with distilled water resulted in moderate germination index (4.85) and was significantly lower than the potassium humate treatment, indicating a positive but less effect on germination effectiveness. Potassium humate-treated seeds experienced a faster mean germination time 4.27 day (Tan., 2024) [54].

Conclusion

The main purpose of seed is to develop into vigorous and healthy plant but seeds can't retain their vigor and viability for a longer time period because they deteriorate rapidly and die. Delayed germination and slower growth of seedlings under different biotic and abiotic stresses not only limit their growth and development but also adversely affect yield and quality. Therefore, application of seed priming will lead to uniform and fast growth of germinated seedlings which is a sustainable approach to enhance agricultural productivity.

References

1. Moradi A, Sohrabiani S, Piri R, Fazeli-Nasab B, Farooq M. Efficacy of priming technique to enhance germination of cumin (*Cuminum cyminum*) seeds of different lifespans. Agrotechniques in Industrial Crops. 2023;3(3):152-161.
2. Amirnia R, Ghiyasi M. Reducing drought stress effects in germination and establishment stage of cumin (*Cuminum cyminum* L.) by seed priming. Journal of Applied Biological Sciences. 2016;10(3):24-26.
3. Anonymous, Spices Statistics, Spice Board, Ministry of Commerce and Industry, Gov. of India, Cochin; c2023.
4. Debbarma A, Devi J, Barua M, Sarma D. Germination performance of chilli (*Capsicum annuum* L.) and coriander (*Coriandrum sativum* L.) as affected by seed priming treatments. Journal of Pharmacognosy and Phytochemistry. 2018;7(1):2648-2652.
5. Arunkumar K, Jegadeeswari V, Ushamalini C. Seed priming technology in spice crops: A review. Journal of Phytology 2019;11:21-24.
6. Verma AK, Singh A, Meena RL, Singh B. Approaches for enhancing salt tolerance in seed spices. In book: Engineering Practices for Management of Soil Salinity., 1st edition, Apple Academic press; c2018. p. 367-401.
7. Bareke T. Biology of seed development and germination physiology. Advances in Plants & Agriculture Research. 2018;8(4):336-346.
8. Mahdavi B. Effects of Priming Treatments on Germination and Seedling Growth of Anise (*Pimpinella anisum* L.). Agricultural Science and Technology Development. 2016;5(3):28-32.
9. Callan NW, Mathre D, Miller JB. Bio-priming seed treatment for biological control of *Pythium ultimum* pre-emergence damping-off in sh-2 sweet corn. Plant Disease. 1990;74:368-372.
10. Christos AD, Spyridon DK, Sideris F. Hydropriming effects on seed germination and field performance of faba bean in spring sowing. Agriculture. 2019;9:201.
11. Bhusal D, Thakur DP. Seed hydropriming technique in cereal crops: A review. Reviews In Food and Agriculture. 2020;1(2):85-88.
12. Dutta P. Seed priming: new vistas and contemporary perspectives. In: Advances in seed priming. Springer Nature, Singapore; c2018. p. 3-22.
13. Farahmandfar E, Bagheri Shirvan M, Azimi Sooran S, Hoseinzadeh D. effect of seed priming on morphological and physiological parameters of fenugreek seedlings under salt stress. International Journal of Agriculture and Crop

Sciences. 2013;8:811-815.
14. Farooq M, Gogoi N, Hussain M, Barthakur S, Paul S, Bharadwaj N, *et al*. Effects, tolerance mechanisms and management of salt stress in grain legumes. Plant Physiology and Biochemistry. 2017;118:199-217.
15. Forti C, Ottobrino V, Bassolino L. Molecular dynamics of pre-germinative metabolism in primed eggplant (*Solanum melongena* L.) seeds. Horticulture Research. 2020;7:87.
16. Fraceto LF, Grillo R, de Medeiros GA, Scognamiglio V, Rea G, Bartolucci C, *et al*. Nanotechnology in agriculture: which innovation potential does it have? Frontiers in Environmental Science. 2016;4:20.
17. Hansaliya D, Parmar L, Viradiya Y, Bhuva J, Thummar M. Effect of seed priming treatment on cumin *Cuminum cyminum* (L.) seed germination and growth. Journal of Applied Horticulture. 2022;24(3):330-332.
18. Singh H, Jassal RK, Kang JS, Sandhu SS, Kang H, Grewal K, *et al*. Seed priming techniques in field crops - A review. Agriculture Review. 2015;36(4):251-264.
19. Heydecker W. Accelerated germination by osmotic seed treatment. Nature. 1973;246:42-44.
20. Khoshvaghti H, Hoseini M, Baser-Kouchehbagh S. Does priming improve dill (*Anethum graveolens*) seed germination and yield? International Journal of Biosciences. 2013;3(7):126-131.
21. Ibrahim EA. Seed priming to alleviate salinity stress in germinating seeds. Journal of Plant Physiology. 2016;192:38-46.
22. Farag IA, Hussein OS, Hassan YE. Improvement seedling growth of celery (A*pium Graveolens* L.) using humic acid, potassium silicate and low gamma irradiation doses. Zagazig Journal of Agricultural Research. 2014;41(4):737-745.
23. Nawaz J, Hussain M, Jabbar A, Nadeem GA, Sajid M, Subtain MU, *et al*. Seed priming- a technique.International Journal of Agriculture and Crop Sciences. 2013;6(20):1373-1381.
24. Wang J, Zhang Y, Zhou L, Yang F, Li J, Du Y, *et al*. Ionizing Radiation: Effective Physical Agents for Economic Crop Seed Priming and the Underlying Physiological Mechanisms. International Journal of Molecular Sciences. 2022;23(23):1-21.
25. Joycy JAA, Rai PK, Lal GM. Effect of different priming methods on seedling parameters of fenugreek (*Trigonella foenumgraecum* L.). Int J Chem Stud. 2018;6(4):202-204.
26. Kamithi KD, Wachira F, Kibe AM. Effects of different priming methods and priming durations on enzyme activities in germinating chickpea (*Cicer arietinum* L.). Am J Nat Appl Sci, 2016, 1.
27. Karimian D. The effect of hydropriming on seedling growth in dill (*Anethum graveolens* L.) at laboratory conditions. Res J Fish Hydrobiol. 2011;6(4):503-506.
28. Bera K, Dutta P, Sadhukhan S. Seed priming with non-ionizing physical agents: plant responses and underlying physiological mechanisms. Plant Cell Rep. 2022;41(1):53-73.
29. Lal G. Scenario, importance and prospects of seed spices: A review. Curr Investig Agric Curr Res. 2018;4(2):491-498.
30. Mahdavi, Rahimi. Seed priming with chitosan improves the germination and growth performance of ajowan (*Carum copticum*) under salt stress. Eur Asian J BioSci. 2013;7:69-76.
31. Shoor M, Afrousheh M, Rabeie J, Vahidi M. The effect of salinity priming on germination and growth stage of Cumin (*Cuminum cyminum* L.). Res J Agric Environ Manag. 2014;3(7):340-352.
32. Mahmood A, Turgay OC, Farooq M, Hayat R. Seed biopriming with plant growth promoting rhizobacteria: a review. FEMS Microbiol Ecol. 2016;92:1-15.
33. Soughir M, Aymen ME, Cherif H. Effect of NaCl priming duration and concentration on germination behavior of fenugreek. Albanian J Agric Sci, 2012, 11(4).
34. Manoj KN, Ghawade SM, Sonkamble AM, Bawkar SO, Phad DS. Effect of seed priming treatments on germination, growth and yield of ajwain (*Trachyspermum ammi* L.). Int J Plant Soil Sci. 2024;36(1):17-23.
35. Thakur M, Sharma P, Anand A. Seed priming-induced early vigor in crops: an alternate strategy for abiotic stress tolerance. In: Priming and pretreatment of seeds and seedlings. Springer Nature, Singapore; c2019. p. 163-184.
36. Mirmazloum I, Kiss A, Erdelyi E, Marta L, Nemeth EZ, Radacsi P, *et al*. The effect of osmopriming on seed germination and early seedling characteristics of Carum carvi L. Agriculture. 2020;10(94):1-11.
37. Mishra BK, Krishna K, Saxena SN, Sharma YK. Effect of biopriming on ajwain (*Trachyspermum ammi* L.) seed germination and vigour. Ann Plant Prot Sci. 2023;31(1):86-91.
38. Mishra BK, Jangir CK, Saxena SN, Sharma YK, Krishna K. Bio-priming: A precision approach to augment seed emergence and yield in Ajwain (*Trachyspermum ammi*) with enhanced soaking agents. Int J Seed Spices. 2022;12(1):48-53.
39. Mirshekari B. Seed priming with iron and boron enhances germination and yield of dill (*Anethum graveolens* L.). Turk J Agric For. 2012;36:27-33.
40. Amir M, Prasad D, Khan FA, Khan A, Ahmad B, Astha, *et al*. Seed priming: An overview of techniques, mechanisms and applications. Plant Sci Today. 2024;11(1):553-556.
41. Rhaman M, Rauf F, Tania SS, Khatun M. Seed Priming Methods: Application in Field Crops and Future Perspectives. Asian J Res Crop Sci. 2020;5(2):8-19.
42. Sarfraz M, Hussain S, Ijaz M, Nawaz A, Yasir TA, Sher A, *et al*. Abiotic stress tolerance in plants by priming and pretreatments with phytohormones. In: Priming and pretreatment of seeds and seedlings- implication in plant stress tolerance and enhancing productivity in crop plants. Springer publications; c2019. p. 447-458.
43. Nakkeeran S, Marimuthu T, Renukadevi P, Brindhadevi S, Jogaiah S. Exploring the biogeographical diversity of Trichoderma for plant health. In: Biocontrol Agents and Secondary Metabolites, Woodhead Publishing; c2021. p. 537-571.
44. Mehra P, Nair R, Jain S. Effect of seed priming with micronutrients on germination of coriander (*Coriandrum sativum* L.) var Jawahar Dhaniya-1. Biol Forum - Int J. 2022;14(2):1298-1302.
45. Rakshit A, Sunita K, Pal S, Singh A, Singh HB. Bio-priming mediated nutrient use efficiency of crop species. In: Nutrient use efficiency: from basics to advances. Springer, New Delhi; c2015. p. 181-191.
46. Ranjeetha R, Raviteja DH. Climate Change: A Never-Ending Disaster. Vigyan Varta. 2023;4(2):105-109.
47. Saxena SN, Kakani RK, Sharma LK, Agrawal D, Rathore SS. Usefulness of hydro-matrix seed priming in cumin (*Cuminum cyminum* L.) for hastening germination. Int J Seed Spices. 2015;5:24-28.
48. Sharma N, Shukla YR, Metha DK. Seed priming and its

consequences on seedling vigour of bell pepper (*Capsicum annuum* L.) under low temperature condition. Int J Bio-res Stress Manag. 2015;6(6):759-764.

49. Sher A, Sarwar T, Nawaz A, Ijaz M, Sattar A, Ahmad S, *et al*. Methods of Seed Priming. In: Priming and Pretreatment of Seeds and Seedlings Implication in Plant Stress Tolerance and Enhancing Productivity in Crop Plants. Springer Nature, Singapore; c2019. p. 1-11.
50. Siavash Moghaddam S, Rahimi A, Noorhosseini SA, Heydarzadeh S, Mirzapour M. Effect of seed priming with salicylic acid on germinability and seedling vigor fenugreek (*Trigonella Foenum-Graecum*). Yuzuncu Yil Univ J Agric Sci. 2018;28(2):192-199.
51. Day S, Kocak-Sahin N. Seed priming with MgCl2, CaCl2, and ZnCl2 as a biofortification based-approach induces changes in anise seedlings emergence. Phyton-Int J Exp Bot. 2023;92(8):2461-2471.
52. Sowjanya S, Dutta A. Pre-sowing seed priming effect on seed quality parameters of coriander (*Coriandrum sativum* L.) under storage condition. J Crop Weed. 2021;17(1):152-158.
53. Lutts S, Benincasa P, Wojtyla L, Kubala S, Pace R, Lechowska K, *et al*. Seed priming: new comprehensive approaches for an old empirical technique. In: New challenges in seed biology - basic and translational research driving seed technology. CBS Publishers; c2016.
54. Tan U. Effects of seed priming on germination of Nigella sativa L. and comparison of germination performance with yield parameters in field conditions. Turk J Agric-Food Sci Technol. 2024;12(6):1026-1032.
55. Warwate SI, Kandoliya UK, Bhadja NV, Golakiya BA. The effect of seed priming with plant growth promoting Rhizobacteria (PGPR) on growth of coriander (*Coriandrum sativum* L.) seedling. Int J Curr Microbiol Appl Sci. 2017;6(3):1926-1934.
56. Wojtyla L, Lechowska K, Kubala S, Garnczarska M. Different modes of hydrogen peroxide action during seed germination. Front Plant Sci. 2016;7:66.
57. Rohamare Y, Dhumal KN, Nikam TD. Response of Ajowan to water stress induced by polyethylene glycol (PEG) 6000 during seed germination and seedling growth. J Environ Biol. 2014;35:789-793.
58. Zhang F, Yu J, Johnston CR, Wang Y, Zhu K, Lu F, *et al*. Seed priming with polyethylene glycol induces physiological changes in sorghum (*Sorghum bicolor* L. Moench) seedlings under suboptimal soil moisture environment. PLOS ONE. 2015;10(10):1-15.