Quest Journals
Journal of Research in Agriculture and Animal Science
Volume 8 ~ Issue 8 (2021) pp: 47-58
ISSN(Online) : 2321-9459
www.questjournals.org

Research Paper

Potentials of Seed Priming for Stress Tolerance: A Review

Lawan Gana Ali[1,] & Abubakar Haruna[1]
Department of Science Laboratory Technology, Mai Idris Alooma Polytechnic Geidam, Yobe State, Nigeria

ABSTRACT
Plants are subjected to so many potentially disturbing environmental stresses such as high and low temperature extremes, submergence, increased salinity, drought, toxic chemicals and so on. These stress factors severely affect different stages of plant growth, development and yield. These days, different techniques are used to produce plants that can tolerate these stress factors. Recently, the simple and cheap technique of seed priming has been developed with a view to imparting tolerance to plants to overcome various environmental stresses. Seed priming is the stimulation of essential physiological and biochemical states in plant through soaking seeds in solutions of natural and synthetic substances to speed up germination processes prior to sowing. In plant defense mechanism, seed priming is a physiological process in which plant adjust more quickly to imminent environmental stresses. Additionally, plants that are produced from primed seeds exhibit robust and faster protective responses against imminent environmental stresses. Seed priming for increased tolerance against abiotic stresses is clearly operating through different pathways that are associated with different processes of metabolism. Different seed priming types are practically used all of which showed primed seeds can giving rise to seedlings which grow faster and uniformly coupled with higher yields. Although there are setbacks of primed seeds in their storability under high temperature leading to low viability when sowed, however the benefit of seed priming outnumber its disadvantages. This review's main objective is to lay an overview of different crop species in which seed priming techniques are applied with their clear benefits against tolerance to burgeoning environmental stresses.

KEYWORDS*: drought stress; salinity; seed germination; seed priming; seedling emergence*

Received 02 August, 2021; Revised: 14 August, 2021; Accepted 16 August, 2021 © The author(s) 2021. Published with open access at www.questjournals.org

I. INTRODUCTION

Plants are naturally exposed to a large array of stresses in the environment during various stages of their development and growth (Lal et al., 2018). The common abiotic stresses that affect plant growth consist of temperature extremes, drought and salinity (Zhao et al., 2007). In agricultural systems, abiotic stresses upon field standing crops cause colossal economic productivity loss and also cause diseases to plants (Jakab et al., 2005). Extreme temperatures, salinity and drought trigger osmotic stress upon crop plants which leads to creating an imbalance at molecular, physiological and cellular levels that finally leads to death of plants. Plants have been able to develop elaborate mechanism which sense stimuli and respond accordingly to the environment resulting to modulating plant metabolites, activating hormone signal pathways which are under the control of plant hormones such as salicylic acid, abscisic acid, ethylene, jasmonate and free radical production (Farooq et al., 2009). Under condition of water deficit, germination of seed and establishment of seedling were hindered due to lowering of water potential that lead to water uptake decline (Farooq et al., 2009). Oxidative injury triggered by the prolific production of reactive oxygen species is yet another key problem plants face due to exposure to drought stress (Gill & Tuteja, 2010). It has become imperative to reduce the harmful effects of water deficit in order to achieve better yields of crops (Ashraf & Rauf, 2001). While responding to both biotic and abiotic environmental stresses, plant produce several volatile organic molecules which play vital roles in essential defense as well as signaling activities. Under stressful situations, the quantity of released volatile organic compounds relies upon stress resistance, duration of time as well as intensity of stresses. Environmental stresses likes salinity and drought are multifaceted traits which are influenced by wide-ranging set of factors. In majority of plants, salinity and drought cause a wide range of physiological, biochemical and metabolic alterations which may lead to oxidative stresses thereby affecting plant metabolic processes, performance which culminate in reduced yield (Shafi, Bakht, & Zhang, 2009; Xiong & Zhu, 2002).

In response to environmental stresses, plant also produce protective enzymes such as superoxide dismutase, catalase, ascorbate peroxidase and proline which destroy ROS generated as a result of stresses. Biogenic volatile organic compounds which are important as signaling and defense molecules are produced by plant (Vickers, Gershenzon, Lerdau, & Loreto, 2009).

Different approaches have been attempted from time immemorial with a view to achieving stress tolerance in plants. Some of these approaches include conventional breeding techniques such as hybridization, selection as well as modern approaches comprising of polyploidy breeding, genetic engineering and mutation breeding and so on. These modern breeding methods are bound to have some limitations such as the need for huge energy and manpower, labour-intensive and are very expensive. Several endeavors to produce varieties of plant with better-quality drought and salinity tolerance employing selection-based strategies of breeding have proven to be hugely unsuccessful mainly due to well-understood multigenic or intricate nature of drought and salinity-resistant characteristics (Cushman & Bohnert, 2000; Flowers et al., 2000). There are innovative techniques such as genetic engineering, plant tissue culture, and priming of seeds which can play important roles in boosting productivity and yield. Genome editing techniques and genetic engineering advanced for inserting targeted foreign genes into crop species of interest can lead to creating improved quality crops (Gust, Brunner, & Nürnberger, 2010). Studies have shown that incorporating transgenes into breeding programmes is not an easy affair due to the disadvantages of gene silencing and the effect of pleiotropy. As a result of the limitation of the modern available technologies, attention and thoughts have been geared to some arrays of alternative techniques such as seed priming, tissue culture and mutagenesis with a view to imparting environmental stress tolerance to plant (Lal et al., 2018). Such alternative techniques have to be simple, cost-effective and can be easily applied by farmers without any manifest complication and should be effective in combating stresses (Jisha, Vijayakumari & Puthur, 2013).

Seed Priming

Seed priming has been one of the crop management techniques used in minimizing the adverse effects of drought stress (Sharma et al., 2014). Priming of seeds has been proven to be effective technique which impart stress tolerance to plant. Seed priming involves exposure of seeds in solutions of hormones, low osmotica, plant nutrients, inorganic salts, water in order to impart of particular physiological, cellular and biochemical states within the seed that improve germination, seedling establishment and stress tolerance (Hussain et al., 2015; Lal et al., 2018). Heydecker, Higgins, & Gulliver (1973) were the first to proposed seed priming theory. It is an effective technique that promotes uniform and rapid emergence of seedling as well as to achieving higher vigour resulting to better crop stands and higher yield. It is a cheap and simple hydration process where seeds are soaked partially in solutions to a point pre-germination metabolic processes are initiated without real seed germination, then dried back to nearly initial dry weight. Priming of seed is practiced for accelerated and quality crop growth and bumper yield in wide range of crops (Yadav, Saini, Pratap, & Tripathi, 2018). Due to the imparted cellular state in seeds as a result of priming, plants raised from these seeds are more resistant to environmental stresses such as drought and salinity (Lal et al., 2018). Seed priming brings about tolerance in plant against attacks by pathogens as well as confers improved defense against diseases. In the past couple of years, priming of seeds has particularly emerged as an effective and pragmatic approach in modern management of biotic and abiotic stresses since it protects plant from pathogen attacks as well as abiotic stresses having not heavily affect plant fitness (Van Hulten et al., 2006). Priming is not only restricted to plants, it can also be used on animals. An example of priming in animals in the typical example of the improved response of the macrophages and monocytes in animals to bacterial lipopolysaccharides. On recognition of bacterial lipopolysaccharides, macrophages and monocytes synthesise a number of cytokines which function in defense against bacteria, viruses, cancerous cells and parasites (Raetz et al., 1991; Jisha et al., 2013). Priming of seeds has been reported to increase nutrient uptake, germination rate as well as regulate seed-related pathogens through inducing pre-germination metabolic processes (Wang et al., 2016). Priming of seeds do promote rapid and synchronous germination coupled with high vigour and better productivity in vegetables, field crops and floriculture (Bruggink et al., 1999; Kaur, Gupta, & Kaur, 2005). Primed seeds show considerably enhanced germination and better uniformity of germination as well as crop performance (Chunthaburee et al., 2014). Various seed priming methods comprising of chemical priming, halopriming, hormone priming, osmopriming, nutrient priming and hydropriming have been use for managing various abiotic stresses in rice plants (Jisha et al., 2013; Paparella et al., 2015). However, it has been reported that osmoprimed maize seeds with urea appeared not have in increased in germination, shoot and radicle dry biomass, germination index and seedling vigour under salinity and drought stresses (Janmohammadi, Dezfuli, & Sharifzadeh, 2008). Ahmed et al. (2016) and Kaya et al. (2006) reported that haloprimed seeds of wheat and hydroprimed seeds of sunflower germinated quicker as well as gave rise to longer seedlings under drought and salinity stresses compared to unprimed seeds. Rapid and uniform germination of primed seeds mainly occur as a result of reduced imbibition lag time, activation of enzymes, synthesis of germination-promoting metabolites, imbibitional repair of metabolic processes as well as osmotic modification (Hussain et al., 2015; Farooq, Basra, Tabassum & Afzal, 2006). It has been reported recently that priming of seeds is beneficial to several crops under chilling stresses. Priming of seeds enhanced chilling tolerance in tobacco plant during stages of germination and growth of seedling due to activation of antioxidant protective systems within the tissues of the plant (Xu, Hu, & Li, 2011). Guan et al. (2009) pointed out that priming of seed increased germination speed and stimulated seedling growth of maize under chilling stress. Similarly, it has been reported that osmopriming and hydropriming triggered improved germination and rapid growth of chickpea plant under chilling temperatures (Elkoca, Haliloglu, & Esitken, 2007). Hussain et al. (2016) reported that two indica rice seeds (HHZ-inbred & YLY6-hybrid) that were osmoprimed, hydroprimed, redox primed and chemical primed under chilling stress were appeared to have increased and faster germination, rapid seedling growth, higher shoot length, root length, and higher fresh weights of shoot and roots compared to unprimed seeds. Likewise, it has been found that hydroprimed and osmoprimed indica and japonica rice seeds produced seedlings with higher soluble sugar quantity, amylase, superoxide dismutase, peroxidase and catalase activities as well as higher content of free proline. Higher activities of these mentioned antioxidants and proline content in primed rice seedlings are indicative of higher tolerance to low temperature stress. Priming of seeds have been reported to increase soluble protein, total soluble sugar and proline under conditions of water stresses compared to unprimed seeds. This technique has been extensively suggested to crop growers in order to boost their crop yields under unfavourable field situations (Yuan-yuan et al., 2010). Thus, there has been strong attention shown by seed companies for finding appropriate priming agents which could be used for enhancing plant tolerance against unfavourable conditions in the fields (Job et al., 2000 in Jisha et al., 2013). Even though priming of seed is the common technique which is mostly reported, plants are likewise be primed at the stage of seedling. In seed priming, seeds are moderately hydrated till process of germination starts, but protrusion of radicle does not ensue (Coolbear & Mcgill, 1990). The main impediments for practical use of primed seeds are viability and storage (McDonald, 2000). Studies have revealed that primed seeds stored at high temperature lose their viability when sown (Hussain et al., 2015). However, seed re-priming and heat shock are reported to enhance viability of primed seeds which are under storage for long period of time at higher temperatures (Hussain et al., 2015). Figure one below shows the mechanisms of seed priming.

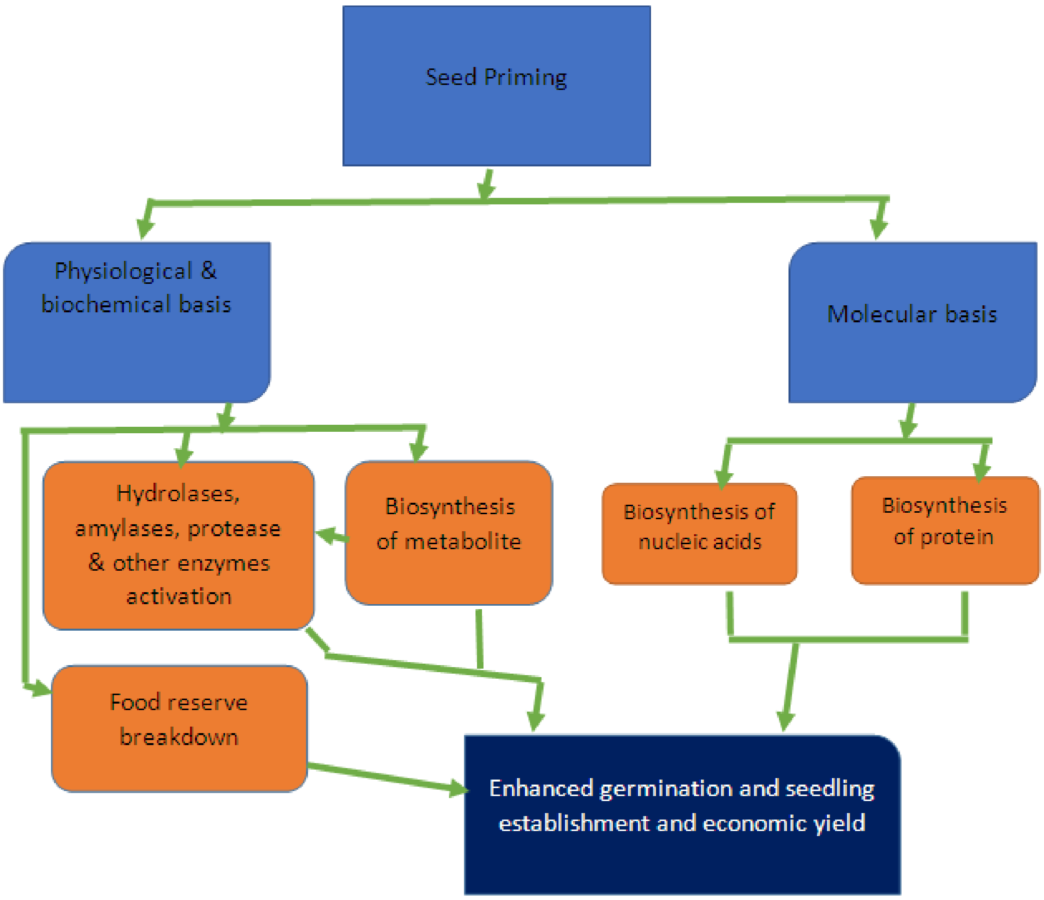

Fig. 2 Mechanism of rice seed priming which lead to fast germination, seedling establishment and economic yield due to seed priming are explained on physiological, biochemical, and molecular bases.
(Farooq et al., 2010)

Factors Influencing Seed Priming.

There are several factors that affect seed priming which consist of light, aeration, seed quality, drying, storage and priming temperature and duration are mostly tested in particular priming experiments.

Air is considered an important factor in a solution of polyethylene glycol to assists in respiration of seed which is necessary for viability of seed and at the same time contributes to uniform seedling emergence. However, the effect of aeration on seed priming differs from one species to another; in onions, air in the solution of PEG enhanced percentage of seed germination compared to control (unaerated treatment). In majority of reviewed literature, aerated priming has been preferred since it guarantees safe habitat for the seed. In smaller scale seed priming experiments, air is mostly provided by means of an aquarium pumps (Di-Girolamo & Barbanti, 2012).

Light has been thought by some literature as having an effect on seed priming systems. In primed lettuce, the better results were achieved having the priming system in the darkness, although photoblastic seed comprising of celery and lettuce require light for germination, thus might be well-lit during the process of priming for dormancy to be reduced (Di-Girolamo & Barbanti, 2012).

Temperature is an essential factor that affects osmotic potential and speediness of chemical reactions. The temperature of 15°C of priming was reported to have enhanced largely the performance of seed germination in some species, however low temperatures have slowed down the processes of germination requiring long duration for the same results to achieve (McDonald, 2000 cited in Di-Girolamo & Barbanti, 2012). The normal temperature range mostly used in priming processes is between 15 to 20°C. Duration of treatment in seed priming is mostly dependent upon the osmotic solution type, temperature, osmotic potential as well as species of crops. A longer duration of priming seeds can cause high susceptibility for emergence of radicle as well as create damages which cannot be reversed on the course of drying seeds back (Parera, Qiao, & Cantliffe, 1993).

It has been reported that seeds of Lehmann love-grass which were imbibed in HO_2 in darkness at 10°C were found to have enhanced percentage of germination as the duration of priming was increased from one day to 3 days (Watts, 2001). Solid matrix priming of seeds at high HO_2 potentials for shorter duration generally triggered improved germination whereas seeds that were primed for longer period of time at lower HO_2 potentials had decreased response to germination. Optimum period of priming seeds vary from one species to another (Hardegree & Emmerich, 1994). Table 1 below presented priming durations for various species of crops, yield benefits recorded and countries tested.

Table 1: Seed priming duration for various species of crops and percentage beneficial effects recorded after priming and countries tested

Crop species	Soaking duration	Yield benefits consistently recorded to date (%)	Countries evaluated
Millet	8	15	India
Mungbean	8	206	Pakistan
Chickpea	8	50	India, Bangladesh, Pakistan, Nepal
Pearl millet	10	56	Pakistan
Sorghum	10	31	Zimbabwe, Pakistan
Maize	12-18	22	Nepal, India, Pakistan, Zimbabwe
Upland rice	12-18	70	Cameroon, Gambia, Sierra Leone, Nigeria, India
Barley	12	40	Pakistan
Wheat	12	37	Pakistan, India, Nepal

(Debbarma & Das, 2017)

Seed Priming Agents

There are various inorganic and organic chemicals such as silicon, nano-silicon particles, potassium nitrate, potassium chloride, calcium chloride used in priming of different seeds of plants for improving seed germination and seedling emergence (Yadav et al., 2018; Yousof, 2013). Variety of solutions such as that of glycerol, polyethylene glycol, calcium chloride and sugars with higher osmotic potentials are used for priming seeds (Yousof, 2013). Plant growth substances are effective in transforming signals associated with stress into gene expression changes required impart adaptation capabilities to plants under unfavourable environmental conditions. Gibberellic acid, salicylic acid as well as kinetin have drawn considerable attention as a result of the beneficial roles they play in triggering plant responses against saline stresses (Afzal et al., 2011). Salicylic acid and kinetin ameliorative roles for inducing salinity tolerance when applied to wheat seeds exogenously or treatment of seeds have been well researched (Jafar et al., 2012).

Different Techniques of Seed Priming and their Consequent Stress Tolerance Effects

Hydropriming

Hydropriming is a simple, cheap and a risk-free technique for the improvement of seed capacity for osmotic adjustment, increasing establishment of seedlings as well as production of crops under stressful environmental conditions (Kaur et al., 2002). With this priming technique, seeds are soaked in clean water or distilled water, then kept for some period of time at suitable temperature and finally dried back prior to sowing. Hydropriming is an important seed enhancement technique for maize inbred lines inducing faster germination of seed under drought and salinity stress (Janmohammadi et al., 2008). It has reported that primed and unprimed rice seed performance differed under drought stress condition while the content of soluble protein and proline were found to be higher in primed seeds than unprimed seeds (Yuan-yuan et al., 2010). Hydropriming of cotton seeds enhanced seed germination under high temperature and water deficit conditions (Casenave &Toselli, 2007).

Osmopriming

Osmopriming is a technique of soaking seed treatment for certain length of time in low osmotic solutions such as polyethylene glycol, sugar, mannitol and so on followed by drying prior to sowing. This technique improves germination of seed as well as improves performance of crops under both normal and salinity stress conditions (Yadav et al., 2018). Under prevailing stress condition like that of salinity, germination percentage as well as germination index decline rapidly with concomitant decrease in the content of chlorophyll a, b and carotenoids in maize plant. Seed priming triggers metabolic alterations during germination which assist in better adaptation under salt stress in sorghum (Aliu et al., 2015). Seeds primed with calcium chloride ($CaCl_2$) and potassium chloride (KCl_2) induce salinity tolerance in cultivar of rice indicated by improved efficiency of germination, growth of seedling, as well as increased dry biomass weight under salty environment (Afzal, 2012). Germination of wheat seeds could be decreased due to exposure to high concentration of sodium chloride (Akbari et al., 2007 in Lal et al., 2018). Seeds primed with hydrogen peroxide exhibited enhanced tolerance to salinity in cultivars of wheat (Wahid, Perveen, Gelani, & Basra, 2007). Seeds of mustard primed with $CaCl_2$, abscisic acid and hydroprimed with water have shown faster germination and the crops produced from primed seeds contain high content of chlorophyll and biomass dry weight under polyethylene glycol (PEG) and NaCl stresses (Srivastava et al., 2010a). Supplementation of *Brassica juncea* roots with thiourea confers tolerance against salinity stress presumably maintenance of water homeostasis (Srivastava et al., 2010b). Potassium nitrate priming and hydropriming significantly enhanced seed germination and growth of seedling under water deficit and salinity stress conditions (Kaya et al., 2006). Winter wheat seeds primed with KCl, water and PEG exhibited faster germination, although priming did not positively affected field emergence (Giri & Schillinger, 2003).

Hormonal Priming

Hormonal priming is the treatment of seed with various hormones such as ascorbate, salicylic acid, gibberellic acid, kinetin and so on with the aim of promoting seedling growth and development (Nawaz et al., 2013). Application of plant growth substances, osmoprotectants or osmolytes exogenously through seed or foliar is a promising strategy for alleviating the harmful effects of salt stresses upon crops (Afzal et al., 2008). Priming of seed, a regulated soaking technique then followed by drying is a practical approach for counteracting the effect of salinity in several crop species due to its low-cost effectiveness and simplicity (Jafar et al., 2012). Heydariyan et al. (2014) reported that seedling grown from primed seeds of Caper (*Capparis spinosa*) with gibberellic acid, salicylic acid and ascorbic acid were observed to have increased rate of germination, germination percentage, shoot length, root length and vigour index of seedling under drought stress compared to seedling from untreated seeds. However, salicylic acid priming affected these agronomic attributes more than the other hormonal priming and as such useful in enhancing germination characteristics of plants in dry and semi-dry areas. The study by Chunthaburee et al., (2014) found that priming of two glutinous rice cultivars (Niewdam & KKU-LLR-039) with spermidine and gibberellic acid alleviated the inhibitory effect of salinity stress by causing increased shoot length, root length, seedling length, seedling fresh weight and dry weight of seedling from primed seeds of both cultivars compared to seedling of the unprimed seeds. Similarly, seedling from primed rice seeds have significantly higher contents of chlorophyll and anthocyanin under saline stress indicating robust photosynthetic activities compared unprimed controls. Primed rice seeds under salinity stress produced seedling with higher content of proline which is associated with protecting plant cellular structures and osmotic adjustment mediating in salt stressed conditions. Salinity stress increased the content of hydrogen peroxide in rice cultivars thereby causing increased lipid peroxidation by inducing higher production of reactive oxygen species, however, spermidine and gibberellic acid primed rice were found to produced seedling with lower content of hydrogen peroxide hence minimal lipid peroxidation compared to untreated seedlings (Chunthaburee et al., 2014). In the study of Sedghi et al. (2010) that primed marigold and sweet fennel were affected by increasing salinity stress thus features including germination percentage, rate and length plumule decreased, however, seedling raised from NaCl and GA_3 primed seeds exhibited low decrease. Among the various levels of salinity, primed seeds showed more rate of germination while seedling raised from primed seeds have longer plumule than seedling from unprimed seeds. Similarly, the highest fresh and dry radicle weights were observed in primed pot marigold at salinity stress level of 7.5dSm-1. The higher rate of germination recorded in pot marigold is an indication of its more salinity tolerance than fennel. Under condition of saline stress, GA_3 and NaCl priming can effect appropriate metabolic reactions within seeds which can enhance performance of seed germination and seedling emergence.

Halopriming

Various seed priming treatments were reported to record improved tolerance to drought to several species of plants. Priming wheat seeds with potassium salts and ascorbic acid enhanced drought tolerance of wheat seedlings (Farooq et al., 2013). Halopriming increases sugarcane cultivars growth under drought and salinity stresses (Patade et al., 2009). Halopriming of mung bean counteracted the effect of salinity stress by increased production of hydrogen peroxide, reactive-oxygen-scavenging enzymes as well as proline accumulation (Saha et al., 2010). Yan, (2015) reported that priming of Chinese cabbage seeds with urea, potassium nitrate and distilled water under drought stress produced seedling with significantly higher percentage of germination, germination potential and seed vigour index. The priming effect stimulated the germination characteristics which were hitherto inhibited by drought severity through modulating higher activities of peroxidase, superoxide dismutase, catalase as well as osmoprotectants proline thereby conferred protection against water deficit compared to seedling from unprimed seeds. Contrarily, soluble sugar content were decreased in both the seedlings from primed and unprimed seeds. Halopriming and redox priming of seeds of two rice cultivars with calcium chloride, potassium chloride and hydrogen peroxide grown under salinity stress produced seedling with increased final germination percentage, shoot length, root length and seedling dry biomass while hydropriming did not affect seedling germination (Afzal et al., 2012). Similarly, rice seed primed with $CaCl_2$, distilled water, KCl_2 and H_2O_2 significantly reduced the length of time taken by seeds to germinate under different range of salinity stress. Salt stress profoundly increased uptake of Na+ in rice cultivars with concomitant increase in concentration of leaf Na+ at higher level of salinity, however, halopriming with calcium chloride increased K^+ in root and leaf but decreased leaf accumulation of Na^+ and root uptake while higher Na^+ take-up and leaf accumulation were observed in seedling from unprimed and H_2O_2 primed seeds. Hitherto decreased chlorophyll content due to increasing salinity level were reported to have higher content of chlorophyll in rice seedling raised from $CaCl_2$ and KCl_2 primed rice seeds compared to lower content of it from seedling raise from hydroprimed and H_2O_2 primed seeds as well as unprimed seeds (Afzal et al., 2012). Priming wheat seeds with $CaCl_2$ was found to enhanced emergence of seedling, establishment of seedling, seedling height, number of grain, tillers, weight of grain as well as productivity under condition of drought stress (Hussian et al., 2013). It has been reported that priming hybrid maize seeds with KNO_3, urea was observed to increased germination potential, growth of seedling, root length, protein and proline quantity under drought and salinity stresses (Anosheh, Sadeghi, & Emam, 2011). Osmoprimed/haloprimed rice seeds with $CaCl_2$ and KCl improves seedling vigour shown by faster germination, emergence of seedling, productive tiller number, kernel yield, harvest index and yield of straw.

Chemical Priming

There are many chemicals that are used in priming seeds of various species of crops. Plants can be imparted with abiotic stress tolerance when treated with some natural compounds or synthetic compounds like chitosan, choline, selenium, paclobutrazol, putrescine, ethanol, potassium dihydrogen phosphate, zinc sulphate, copper sulphate and butenolide (Demir, Ozuayd, Yasar, & Staden, 2012; Foti et al., 2008; Guan, Hu, Wang, & Shao, 2009; Su et al., 2006; Wang et al., 2016) Butenolide has been reported to increases vigour of seedlings of several species of crops and enhances emergence of seedlings in *Salvia L.* and *Capsicum annum* L. (Demir et al., 2012). Compound of butenolide was extracted from burnt cellulose and plant-derived smoke. The improved as well as fast seedling establishment due butenolide treatment decreases susceptibility of pathogen attack. Priming seeds of rice with silicon considerably decreased rice root attacks by nematode (*Meloidogyne graminicola*) as well as delay nematode development, while there was no clear observable effects on giant cells. Improved silicon primed rice plants' resistance to nematode attacks was correlated with high levels transcript defense-linked genes of *OsERF*1, *OsEIN*2 as well as *OsACS*1 within the ethylene pathways. Priming with silicon significantly decreased number of nematodes within rice plants plus increased ethylene signaling, although no such effect in plants deficit of ethylene signaling suggesting that silicon priming effect was dependent upon ethylene pathway (Zhan et al., 2018). Rice varieties primed with selenium under arsenic stress were found to have depressive effects on the stress and markedly increased plant height, weight of panicles, number of grain, 1000-grain weight, chlorophyll content as well as above-soil biomass compared to unprimed seedlings (Moulick, Santra & Ghosh, 2018).

Nutrient Priming

There have been several attempts underway with a view to unravelling new and effective priming agents. Utilization of micro or trace elements such as boron and zinc has drawn attention in priming experiments. Presoaking seeds in solution of selenium has been an approach that provides the element to plants in order to effects growth regulation (Khaliq et al., 2015). Seed priming with nutrients has been a novel approach which combines the beneficial effects of enhanced nutrient supply and seed priming (Al-Mudaris & Jutzi, 1999). In priming seeds with nutrients, seeds are soaked in solutions that contains limiting quantity of nutrients than soaking in only water (Arif et al., 2005). Burgeoning evidence indicate that plant nutrient such as iron, manganese and zinc are critically important in impacting tolerance to higher plants against abiotic and biotic stress factors (Marschner, 2012 cited in Imran et al., 2013). Among mineral nutrients, potassium, silicon and selenium are playing particularly vital roles in crop plants survival under prevailing stressful environmental conditions (Amalina, Zain, & Razi, 2016; Azeem et al., 2015; Wang et al., 2016). Priming of seeds in solution of zinc enhances grain productivity of wheat and chickpea (Arif, Waqas, & Nawab, 2007). Ascorbic acid, an essential vitamin can be used for priming seeds because of its antioxidant properties. It has been proven earlier that high amount endogenous ascorbate plays an important role in maintenance of antioxidant capability which offers protection to plants against oxidative damages (Farooq et al., 2006). Pretreatment of wheat grass (*Agropyron elongatum*) with ascorbic acid under salinity stress improved its germination characteristics (Tavili, Zare & Enayati, 2010). Imran et al. (2013) studied nutrient priming and hydropriming of maize with iron and Zn+Mn under laboratory and field conditions where the results showed that nutrient primed maize was found to have considerably increased seedling fresh biomass, shoot and root length under low root zone temperature. However, there was no difference between hydroprimed maize and unprimed maize. Similarly, on the field, Zn+Mn priming promoted maize seedling growth and nutrient status more than Fe priming and hydropriming. Moulick, Santra and Ghosh (2018) studied selenium (Se) priming of two varieties of rice (Swarna & Satabdi) under arsenic stress where it was found that all Se doses (0.5 Mg L, 0.75 Mg L & 1.0 Mg L) priming significantly enhanced plant height, biomass, panicle weight, number of tiller and content of chlorophyll a, b and c. Enhancement of these growth parameters were dose dependent-higher dose of 1.0 Mg L was more effective in increasing these growth attributes. Se priming was also effective in restricting arsenic translocation to different plant aerial parts. In the study of Wang et al. (2016) that selenium and salicylic acid priming of two rice varieties under chilling stress found that rice seedling growth was improved depicted by increase in shoot length, root length, shoot fresh biomass and root fresh biomass. Similarly, both Se and SA primed rice varieties have maximum emergence of 81.87% and 80% with improved germination of 87.5% and 82.81%. The study of Khaliq et al. (2015) on priming two rice cultivars (Super basmati & Shaheen basmati) with concentrations of 15, 30, 45, 60, 75, 90 and 105 μmol L Se found that mean emergence time and time to attain 50% emergence were significantly decreased and increased emergence index compared to hydroprimed and control rice seeds. However, 60 and 75 μmol L Se priming were more effective in decrease of these attributes. Moreover, Se priming was found to increased shoot length, root length and dry biomass of Super basmati and Shaheen rice seedlings more than hydroprimed and their unprimed control rice seedling counterparts.

Magnetopriming

The technique of exposing seeds of various crop species into magnetic flux density to initiate essential germination processes is an effective and safe dry priming method which has been found to speed up germination and increase germination rate and seedling vigour of diverse species of crops (Thomas, Anand, & Chinnusamy, 2013). Several literature reported metabolic changes that take place in germinating seeds due to magnetopriming under normal environmental conditions (Bhardwaj, Anand, & Nagarajan, 2012; Shine, Guruprasad, & Anand, 2011). In the study by Thomas et al. (2013), it was found that magnetopriming of two chickpea varieties-Pusa 1053 & Pusa 256 to 100 mT (militesla) for one hour, then exposed to varying degrees of salinity and normal conditions markedly enhanced germination percentage, germination rate as well as seedling growth by improving shoot length, root length and seedling vigour indices I and II compared to unprimed chickpea seeds. The study further revealed that primed chickpea varieties exhibited higher water imbibition under both normal and salt stress conditions, a process that stimulate faster germination and seedling growth. It has been reported that seeds of sunflower (*Helianthus annus* L.), field pea (*Pisum sativum* L.), flax (*Linum usitatissimum* L.) and buckwheat (*Fagopyrum esculentum* Moench.) subjected to static magnetic field gave rise to early and fast growing seedlings (Gubbel, 1982 cited in Thomas et al., 2013). Low quality seeds exposed to magnetic field were reported to have improved quality as well as germination rate (Carbonell, Carbonnel, Maqueda, & Amaya, 2008). Magnetopriming was found to be effective in ameliorating damaging effects of drought stress in seedlings of maize (Anand et al., 2012). Vashisth and Nagarajan, (2010) reported that sunflower and wheat seeds exposed to static magnetic field were observed to have considerably higher activity of amylase compared to controls. According to the study by Hozayn, El-Mahdy and Zalama (2018), that magnetopriming in combination with proline and arginine of barley (*Hordeum vulgare* L.) under different levels of salt stresses showed that primed seeds significantly have higher germination percentage, germination index, germination rate and shorter mean germination compared to unprimed seeds. However, these declined as salt stress levels increased.

Biopriming

Biopriming of pea seeds with aqueous extract of lesser bulrush was found to have caused increased rate of germination, seedling growth, shoot length and root length through ameliorating the adverse effects of salinity thereby increasing the contents of proline, total soluble sugar, chlorophylls a & b, carotenoids, total phenolic, total flavonoid while reduction of malondialdehyde content in the plants from primed seeds compared to plants from untreated seeds. However, content of alkaloid was found to have decreased in seedling from unprimed pea seeds (Ghezal et al., 2016). Biopriming was reported in controlling seedling damping off in sweet corn (*Zea mais* L.), pea (*Pisum sativum*), cucumber (*Cucumis melo* L.), and soya beans (*Glycine max* L.) (Girolamo & Barbanti, 2012). Singh et al. (2016) conducted a field study on biopriming pea seeds with *Trichoderma asperellum*. The results of the study indicated that biopriming has significantly increased number of pea leaves, shoot length, fresh and dry weight of shoot, fresh and dry weight of root, root length compared to unprimed peas. Biopriming is important in giving protection to the seedlings against infections, diseases and pest attacks. Rice seed (cv. MDU) biopriming experiments by Sivakumat et al. (2016) using Phosphobacteria of concentrations 10, 15 and 20% for 6, 12, 18 and 24 hours under laboratory condition showed that all the bioprimed seeds have higher germination speed, germination percentage, shoot length, root length, seedling dry biomass and seed vigour index compared. However, among all the Phosphobacteria concentrations, 20% at 24 hours biopriming has given the best results of the parameters studied while the lowest results of all the parameters studied were recorded by the seedlings from unprimed seeds.

Solid Matrix Priming

Solid matrix priming is another technique of seed hydration which involves using a semi-solid inorganic or organic materials to simulate the processes of natural imbibition taking place within the soil environment. Substrates for matrix priming must possess the given features including higher safety of seed, lower matric potential, high surface/volume ratio, minimum water solubility, high water holding capacity and ability of adhering to surface of seeds. Vermiculite or peat, marketable substrates like Micro-cel and Celite are the materials used in solid matrix priming of seeds (Di-Girolamo & Barbanti, 2012). In solid matrix priming, the seeds have to be mixed together with the substrates that slowly wet the seeds. In improving seed imbibition control, the pure water has to be changed with a low osmotic solution similar to that of osmotic priming (Di-Girolamo & Barbanti, 2012). There are numerous reports noting the beneficial effects of solid matrix priming on crop species. Solid matrix priming was found to increased carrot field performance and enhanced soybean germination and seedling vigour (Lutts et al., 2016). Study has revealed that matrix priming increased rate of seed germination, seedling establishment as well as growth of onion under normal and chilling temperature conditions (Kepczynska et al., 2003). It has been reported that combining biological and chemical priming with solid matrix priming may considerably increase performance of seeds (Sen & Mandal, 2016). Matriconditioning integrated with *Bacillus subtilis*, fungicide and gibberellins led to increased crop establishment and yield in certain species of vegetables grown in the tropics (Andreoli & Andrade, 2002). Furthermore, GA_3 matri-conditioning was found to increased hot pepper seed quality (Ilyas, 2006). Solid matrix priming combined with species of *Trichoderma viride* enhanced germination percentage, field of emergence of seedlings, fruits per plant and productivity of okra grown under chilling temperature conditions (Pandita et al. 2010). According to Sarkar et al. (2018) solid matrix priming and 1% KNO_3 priming of bamboo (*Dendrocalamus strictus*) for 8 hours were effective for increasing germination percentage, shoot and root lengths, leaf length and width as well as germination speed. The study by Sen & Mandal (2016) found that matrix-aided chitosan priming of mung beans and grown under saline conditions has promoted higher germination index, germination speed, coefficient germination velocity, low mean germination duration coupled with higher germination stress resistance, plant height stress resistance and root length stress resistance indices compared to unprimed mung bean seedlings. However, under higher salinity stress of above 12 dSm (deci Siemens metre), no significant effect of priming on these features.

Disadvantages of Seed Priming

Seed priming decreases the lifespan of primed seeds immensely compared to unprimed seeds. It has been reported that primed seeds can easily deteriorate in storage if the temperature is high. Primed sweet maize seeds showed poor germination as well as growth performance of seedlings after stored for 3 months at 25°C compared to unprimed seeds (Chiu, Chen, & Sung, 2002; Hussain et al., 2015) Lower and delayed germination had been observed in primed tomato seeds stored for 6 months at 30°C compared to control seeds. Primed lettuce seeds were reported to have reduced longevity in storage at higher temperature and humidity relative to unprimed seeds. Primed lettuce seeds stored for 14 days in mild conditions of 45°C and 50% relative humidity showed delayed and non-uniform germination than unprimed (Hill et al., 2007; Schwember & Bradford, 2005).

Studies have pointed out that the better qualities of primed seeds stored at 25°C could be maintained for the period of only 15 days after which their agronomic performance is less than that of unprimed seeds. This deteriorative effect of stored primed seeds at 25°C are attributed to hampered metabolism of starch (Hussain et al., 2015). It has been reported that priming of onion prior to storage helps in delay of viability loss, after storage priming had no any implication on seed viability. Primed and dried seeds of onion have retained germination improvement potentials even after the period of 18 months stored at 10 °C (Hussain et al., 2015). Chiu et al. (2002) has pointed out that primed seeds of sweet corn in storage for longer than 12 months at −80 or 10°C were observed to have shown higher longevity as well as exhibited quality germination and better seedling vigour responses compared to unprimed seeds. Differences in longevity of primed seeds are due to the interplay of genetic and environmental factors such as seed water content, seed storage temperature and quality of seeds. High temperature and seed water content have been known to accelerate further rate of deterioration of seeds (Hussain et al., 2015). Hussain et al. (2015) pointed out that two primed Indica rice (HHZ, inbred & YLY6, hybrid) seeds with 10% polyethylene glycol and 0.5mmolL spermidine for 24 hours at 25 °C subjected to 210 days storage at 25 and −4°C were observed that those stored at 25°C greatly lost seed germinability where only 3.6 and 21.3% of the two primed rice seeds germinated. However, primed rice seeds in −4°C storage for 210 days had similar germination performance with un-stored seeds. Though unprimed rice seeds (HHZ, inbred & YLY6, hybrid) stored at 25°C were observed to have decreased germination by about 7.6 and 9.3%; but negative impacts were lower when compared with that of primed seeds. Similar trends of reduction of shoot length, root length and seedling fresh biomass from polyethylene and spermidine primed Indica rice seeds stores 25°C for 210 days compared to un-stored rice seeds and rice seeds stored at −4°C (Hussain et al., 2015). However, it has been reported that decreased durability of primed seeds could be restored partially by application of post-storage treatments like dehydration, heat shock, priming and humidification. Repeated priming of seeds after being stored can help minimize the destructive impacts of storage on viability of seeds.

II. CONCLUSIONS

The technique of priming seed in the past couple of years was viewed as a reliable approach for managing stresses as it helps protect plants from various stress types which might gravely affect their fitness. In addition, this technique offers an effective, realistic, smart and simple option of plant protection. High temperature, oxidative stress, salinity and drought are all interconnected and may trigger damages of similar nature. Consequently, these abiotic stresses mostly activate similar cellular signaling pathways and responses. Seed priming is known to activate these cellular responses in plant early stages of development and growth eventually lead to quick defense responses. The precise molecular processes behind seed priming is not fully unraveled, it is however, speculated that it is due to inactive protein accumulation in primed cells. Several views were put forward on seed priming effectiveness. Nascimento and West (1988) reported that enhance germination and seedling vigour of primed seeds is because of food reserve mobilization, activation and synthesis of certain enzymes as well as elevated production of DNA and RNA.

ACKNOWLEDGEMENT

This piece of work is sponsored by Tertiary Education Trust Fund Nigeria (TETFUND Nig.), due appreciation to this organization and management of Mai Idris Alooma Polytechnic Geidam, Yobe State for the consideration. I also thank Assoc. Professor Dr. Rosimah Nulit of the Department of Biology, Universiti Putra Malaysia for correcting the write-up.

REFERENCES

[1]. Afzal, I., Butt, A., Rehman, H. U., Maqsood, S., Basra, A., & Afzal, A. (2012). Alleviation of salt stress in fine aromatic rice by seed priming. *Australian Journal of Crop Science*, *6*(10), 1401–1407.

[2]. Afzal, I., Hussain, B., Shahzad, B., & Rehman, H. (2012). MAIZE SEED PRIMING WITH MORINGA LEAF EXTRACT Priming with moringa leaf extract reduces imbibitional chil .... *Seed Science and Technology*, *40*, 271–276. https://doi.org/10.15258/sst.2012.40.2.13

[3]. Afzal, I., Rauf, S., Basra, S. M. A., & Murtaza, G. (2008). Halopriming improves vigor , metabolism of reserves and ionic contents in wheat seedlings under salt stress. *PLANT SOIL ENVIRON.*, *54*(9), 382–388.

[4]. Afzal, I., Basra, S.M.A., Ahmad, N., Cheema, M.A., Haq, M.A., M. H. Kazmi M. H. and Irfan, S. (2011). Enhancement of Antioxidant Defense System Induced by Hormonal Priming in Wheat. *Cereal Research Communications*, *39*(3), 334–342. https://doi.org/10.1556/CRC.39.2011.3.3

[5]. Ahmed, M., Qadeer, U., Ahmed, Z. I., & Hassan, F. U. (2016). Improvement of wheat (Triticum aestivum) drought tolerance by seed priming with silicon. *Archives of Agronomy and Soil Science*, *62*(3), 299–315. https://doi.org/10.1080/03650340.2015.1048235

[6]. Aliu, S., Rusinovci, I., Fetahu, S., Gashi, B., Simeonovska, E., & Rozman, L. (2015). The effect of salt stress on the germination of maize (Zea mays L .) seeds and photosynthetic pigments. *Acta Agriculturae Slovenica*, *105*(1), 85–94. https://doi.org/10.14720/aas.2015.105.1.09

[7]. Al-Mudaris, M. A. & Jutzi, S. C. (1999). The Influence of Fertilizer- based Seed Priming Treatments on Emergence and Seedling Growth of Sorghum bicolor and Pennisetum glaucum in Pot Trials under Greenhouse Conditions. *Journal of Agronomy & Crop Science*, *182*, 135–141.

[8]. Amalina, N., Zain, M., & Razi, M. (2016). Effects of potassium rates and types on growth , leaf gas exchange and biochemical changes in rice (Oryza sativa) planted under cyclic water stress. *Agricultural Water Management*, *164*, 83–90. https://doi.org/10.1016/j.agwat.2015.09.022

[9]. Anand, A., Nagarajan, S., Verma, A. P. S., Joshi, D. K., Pathak, P. C., & Bhardwaj, J. (2012). Pre-treatment of seeds with static magnetic field ameliorates soil water stress in seedlings of maize (Zea mays L .). *Indian Journal of Biochemistry & Biophysics*, *49*, 63–70.

[10]. Anosheh, H. P., Sadeghi, H., & Emam, Y. (2011). Chemical Priming with Urea and KNO 3 Enhances Maize Hybrids (Zea mays L .) Seed Viability under Abiotic Stress. *Journal of Crop Science and Biotechnology*, *14*(4), 289–295.

[11]. Arif, M., Sajid A., Asad S., Naseem J. & Rashid, A. (2005). Seed priming maize for improving emergence and seedling growth. *Sarhad Journal of Agriculture*, *21*(4).

[12]. Arif, M., Waqas, M., & Nawab, K. (2007). Effect of seed priming in Zn solutions on chickpea and wheat Effect of seed priming in Zn solutions on chickpea and wheat. In *African Crop Science Conference Proceedings, Egypt* (pp. 237–240).

[13]. Ashraf, M., & Rauf, H. (2001). Inducing salt tolerance in maize (Zea mays L.) through seed priming with chloride salts: Growth and ion transport at early growth stages. *Acta Physiologiae Plantarum*, *23*(4), 407–414. https://doi.org/10.1007/s11738-001-0050-9

[14]. Azeem, M., Iqbal, N., Kausar, S., Javed, M. T., Akram, M. S., & Sajid, M. A. (2015). Efficacy of silicon priming and fertigation to modulate seedling's vigor and ion homeostasis of wheat (Triticum aestivum L.) under saline environment. *Environmental Science and Pollution Research*, *22*(18), 14367–14371. https://doi.org/10.1007/s11356-015-4983-8

[15]. Bhardwaj, J., Anand, A., & Nagarajan, S. (2012). Plant Physiology and Biochemistry Biochemical and biophysical changes associated with magnetopriming in germinating cucumber seeds. *Plant Physiology and Biochemistry*, *57*, 67–73. https://doi.org/10.1016/j.plaphy.2012.05.008

[16]. Bruggink, G. T., Ooms, J. J. J., Toorn, P. Van Der, Bruggink, G. T., Ooms, J. J. J., & Toorn, P. Van Der. (1999). Induction of longevity in primed seeds. *Seed Science Research*, *9*, 49–53. https://doi.org/10.1017/S0960258599000057

[17]. Carbonell, M. V, Carbonnel, M. V, Maqueda, R., & Amaya, J. M. (2008). Magnetic field treatments improve germination and seedling growth in Festuca arundinacea Schreb . and Lolium perenne L . *Seed Science and Technology*, *36*, 31–37.

[18]. Casenave, E.C. and Toselli, M.E. (2007). Hydropriming as a pre-treatment for cotton germination under thermal and water stress conditions. *Seed Science and Technology*, *35*, 88–98. https://doi.org/10.15258/sst.2005.33.1.09

[19]. Chiu, K. Y., Chen, C. L., & Sung, J. M. (2002). Effect of Priming Temperature on Storability of Primed sh-2 Sweet Corn Seed. *Crop Science*, *42*, 1996–2003.

[20]. Chunthaburee, S., Sanitchon, J., Pattanagul, W., & Theerakulpisut, P. (2014). Alleviation of salt stress in seedlings of black glutinous rice by seed priming with spermidine and gibberellic acid. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *42*(2), 405–413. https://doi.org/10.1583/nbha4229688

[21]. Coolbear, P., & Mcgill, C. R. (1990). Effects of a low-temperature pre-sowing treatment on the germination of tomato seed under temperature and osmotic stress. *Scientia Horticulturae*, *44*, 43–54.

[22]. Cushman, J. C., & Bohnert, H. J. (2000). Genomic approaches to plant stress tolerance. *Current Opinion in Plant Biology*, *3*, 117–124.

[23]. Debbarma, M., & Das, S. P. (2017). Priming of Seed : Enhancing Growth and Development. *International Journal of Current Microbiology & Applied Sciences*, *6*(12), 2390–2396.

[24]. Demir, I., Ozuayd, I., Yasar, F., & Staden, J. Van. (2012). Effect of smoke-derived butenolide priming treatment on pepper and salvia seeds in relation to transplant quality and catalase activity. *South African Journal of Botany*, *78*, 83–87. https://doi.org/10.1016/j.sajb.2011.05.009

[25]. Di-Girolamo, G. & Barbanti, L. (2012). Treatment conditions and biochemical processes influencing seed priming effectiveness. *Italian Journal of Agronomy*, *7*(25). https://doi.org/10.4081/ija.2012.25

[26]. Elkoca, E., Haliloglu, K., & Esitken, A. (2007). Hydro and ospriming improve chickpea germination. *Acta Agriculturae Scandinavia Section B-Soil and Plant Science*, *57*, 193–2000. https://doi.org/10.1080/09064710600914087

[27]. Farooq, M., Basra, S. M. A., Tabassum, R., & Afzal, I. (2006). Enhancing the Performance of Direct Seeded Fine Rice by Seed Priming. *Plant Production Science*, *9*(4), 446–456. https://doi.org/10.1626/pps.9.446

[28]. Farooq, M., Basra, S. M. A., Wahid, A., Khaliq, A., & Kobayashi, N. (2010). Rice Seed Invigoration : A Review. In *Sustainable Agriculture Reviews* (pp. 137–175). https://doi.org/10.1007/978-1-4020-9654-9

[29]. Farooq, M., Irfan, M., Aziz, T., Ahmad, I., & Cheema, S. A. (2013). Seed Priming with Ascorbic Acid Improves Drought Resistance of Wheat. *Journal of Agronomy and Crop Science*, *199*(1), 12–22. https://doi.org/10.1111/j.1439-037X.2012.00521.x

[30]. Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. M. A. (2009). Plant drought stress: Effects, mechanisms and management. *Sustainable Agriculture*, *29*, 153–188. https://doi.org/10.1007/978-90-481-2666-8_12

[31]. Flowers, T. J., Koyama, M. L., Flowers, S. A., Sudhakar, C., Singh, K. P., & Yeo, A. R. (2000). QTL : their place in engineering tolerance of rice to salinity. *Journal of Experimental Botany*, *51*(342), 99–106. https://doi.org/10.1093/jexbot/51.342.99

[32]. Foti, R., Abureni, K., & Tigere, Albert, Jephita Gotosa, J. G. (2008). The efficacy of different seed priming osmotica on the establishment of maize (Zea mays L .) caryopses. *Journal of Arid Environments*, *72*, 1127–1130. https://doi.org/10.1016/j.jaridenv.2007.11.008

[33]. Ghezal, N., Rinez, I., Sbai, H., Saad, I., Farooq, M., Rinez, A., … Haouala, R. (2016). Improvement of Pisum sativum salt stress tolerance by bio-priming their seeds using Typha angustifolia leaves aqueous extract. *South African Journal of Botany*, *105*, 240–250. https://doi.org/10.1016/j.sajb.2016.04.006

[34]. Gill, S. S., & Tuteja, N. (2010). Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Plant Physiology and Biochemistry*, *48*(12), 909–930. https://doi.org/10.1016/j.plaphy.2010.08.016

[35]. Giri, G. S. & Schillinger, W. F. (2003). Seed Priming Winter Wheat for Germination , Emergence , and Yield. *Crop Science Society of America*, (43), 2135–2141.

[36]. Guan, Y., Hu, J., Wang, X., & Shao, C. (2009). Seed priming with chitosan improves maize germination and seedling growth in relation to physiological changes under low temperature stress *. *Journal of Zhejiang University SCIENCE*, *10*(6), 427–433. https://doi.org/10.1631/jzus.B0820373

[37]. Gust, A. A., Brunner, F., & Nürnberger, T. (2010). Biotechnological concepts for improving plant innate immunity. *Current Opinion in Biotechnology*, *21*(2), 204–210. https://doi.org/10.1016/j.copbio.2010.02.004

[38]. Hardegree, S. & Emmerich, P. (1994). Drying and storage effects on germination primed grass seeds. *Journal of Range Management, 47*, 196–199.

[39]. Heydariyan, M., Basirani, N., Sharifi-Rad, M., Khmmari, I. & Poor, S.R. (2014). Effect of Seed Priming on Germination and Seedling Growth of the Caper (Capparis Spinosa) Under Drought Stress. *International Journal of Advanced Biological and Biomedical Research*, *2*(8), 2381–2389.

[40]. Heydecker, W., Higgins, J., & Gulliver, R. L. (1973). Accelerated germination by osmotic seed treatment. *Nature*, *246*(5427), 42–

44. https://doi.org/10.1038/246042a0

[41]. Hill, H. J., Cunningham, J. D., Bradford, K. J., & Taylor, A. G. (2007). Primed Lettuce Seeds Exhibit Increased Sensitivity to Moisture Content During Controlled Deterioration. *Horticultural Science*, *42*(6), 1436–1439.

[42]. Hozayn M., El-Mahdy, A.A. & Zalama, M.T. (2018). Magneto-priming for improving germination , seedling attributes and field performance of barley (Hordeum vulgare L .) under salinity stress. *Middle East Journal of Agriculture Research*, *7*(3), 1006–1022.

[43]. Hussain, S., Khan, F., Hussain, H.A., Nie, L. (2016). Physiological and Biochemical Mechanisms of Seed Priming-Induced Chilling Tolerance in Rice Cultivars. *Frontiers in Plant Science*, *7*, 1–14. https://doi.org/10.3389/fpls.2016.00116

[44]. Hussain, S., Zheng, M., Khan, F., Khaliq, A., Fahad, S., Peng, S., … Nie, L. (2015). *Benefits of rice seed priming are offset permanently by prolonged storage and the storage conditions*. *Scientific Reports* https://doi.org/10.1038/srep08101

[45]. Hussian, I., Ahmad, R., Farooq, M., & Wahid, A. (2013). Seed Priming Improves the Performance of Poor Quality Wheat Seed. *International Journal of Agriculture & Biology*, *15*, 1343–1348.

[46]. Ilyas, S. (2006). Review : Seed Treatments Using Matriconditioning to Improve Vegetable Seed Quality. *Bulletin of Agronomy*, *34*(2), 124–132.

[47]. Imran, M., Mahmood, A., Römheld, V., & Neumann, G. (2013). Nutrient seed priming improves seedling development of maize exposed to low root zone temperatures during early growth. *European Journal of Agronomy*, *49*, 141–148. https://doi.org/10.1016/j.eja.2013.04.001

[48]. Jafar, M. Z., Farooq, M., Cheema, M. A., Afzal, I., Basra, S. M. A., Wahid, M. A., … Shahid, M. (2012). Improving the performance of wheat by seed priming under saline conditions. *Journal of Agronomy and Crop Science*, *198*(1), 38–45. https://doi.org/10.1111/j.1439-037X.2011.00485.x

[49]. Jakab, G., Ton, J., Flors, V., Zimmerli, L., Metraux, J. & Mauch-Mani, B. (2005). Enhancing Arabidopsis Salt and Drought Stress Tolerance by Chemical Priming for Its Abscisic Acid Responses1. *Plant Physiology*, *139*(September 2005), 267–274. https://doi.org/10.1104/pp.105.065698.various

[50]. Janmohammadi, M., Dezfuli, P. M., & Sharifzadeh, F. (2008). SEED INVIGORATION TECHNIQUES TO IMPROVE GERMINATION AND EARLY GROWTH OF INBRED LINE OF MAIZE UNDER SALINITY AND DROUGHT. *Genetics & Applied Plant Physiology*, *34*(3–4), 215–226.

[51]. Jisha K. C., Vijayakumari, K. & Puthur, J. T. (2013). Seed priming for abiotic stress tolerance : an overview. *Acta Physiol Plant*, *35*, 1381–1396. https://doi.org/10.1007/s11738-012-1186-5

[52]. Kaur, S., Gupta, A. K., & Kaur, N. (2002). Effect of osmo- and hydropriming of chickpea seeds on seedling growth and carbohydrate metabolism under water deficit stress. *Plant Growth Regulation*, *37*, 17–22.

[53]. Kaur, S., Gupta, A. K., & Kaur, N. (2005). Seed Priming Increases Crop Yield Possibly by Modulating Enzymes of Sucrose Metabolism in Chickpea. *J. Agronomy & Crop Science*, *191*, 81–87.

[54]. Kaya, M. D., Okc, G., Atak, M., & Yakup, C. O. K. (2006). Seed treatments to overcome salt and drought stress during germination in sunflower (Helianthus annuus L .). *European Journal of Agronomy*, *24*, 291–295. https://doi.org/10.1016/j.eja.2005.08.001

[55]. Kepczynska, E., Piekna-Grochala, J. & Kepczynnski, J. (2003). Effects of matriconditioning on onion seed germination , seedling emergence and associated physical and metabolic events. *Plant Growth Regulation*, *41*, 269–278.

[56]. Khaliq, A., Aslam., Matloob A., Hussain, S., Geng, M., Wahid, A. & Rehman, H. (2015). Seed Priming with Selenium : Consequences for Emergence , Seedling Growth , and Biochemical Attributes of Rice. *Biological Trace Element Resorces*. https://doi.org/10.1007/s12011-015-0260-4

[57]. Lal, S. K., Kumar, Sheri., V., Mehta, S., Varakumar, P., Ram., B., Borphukan, B., James, Fartyal, D. & Reddy, M. K. (2018). Seed Priming: An Emerging Technology to Impart Abiotic Stress Tolerance in Crop Plants. *Advances in Seed Science*. https://doi.org/10.1007/978-981-13-0032-5

[58]. Lutts, S., Benincasa, P., Wojtyla, L., Lechowska, K., & Quinet, M. (2016). " Seed priming : new comprehensive approaches for an old empirical technique " Référence bibliographique Seed Priming : New Comprehensive Approaches for an Old Empirical Technique.

[59]. Moulick, D., Santra, C. S. and Ghosh, D. (2018). Seed priming with Se mitigates As-induced phytotoxicity in rice seedlings by enhancing essential micronutrient uptake and translocation and reducing As translocation. *Environmental Science and Pollution Research*.

[60]. https://doi.org/10.1016/j.jhazmat.2018.05.017

[61]. Nascimento W. M. & West, S. H. (1988). Priming and Seed Orientation Affect Seedcoat Adherence and Seedling Development of Muskmelon Transplants. *Hort. Science*, *33*(5), 847–848.

[62]. Nawaz, J., Hussain, M., Jabbar, A., Nadeem, G. A., Sajid, M., Subtain, M., & Shabbir, I. (2013). Seed Priming A Technique. *International Journal of Agriculture and Crop Sciences*, *6*(20), 1373–1381. https://doi.org/10.1016/j.fcr.2004.04.006

[63]. Pandita, V. K., Anand, A., Nagarajan, S., Seth, R., & Sinha, S. N. (2010). Solid matrix priming improves seed emergence and crop performance in okra. *Seed Science and Technology*, *38*, 665–674.

[64]. Paparella, S., Araujo, S.S., Rossi, G., Wijayasinghe, M., Carbonera, D., B. A. (2015). Seed priming : state of the art and new perspectives. *Plant Cell Rep*. https://doi.org/10.1007/s00299-015-1784-y

[65]. Parera, C. A., Qiao, P., & Cantliffe, D. J. (1993). Enhanced Celery Germination at Stress Temperature via Solid Matrix Priming. *Hortscience*, *28*(1), 20–22.

[66]. Patade, V. Y., Sujata Bhargava, S. & Suprasanna, P. (2009). Agriculture , Ecosystems and Environment Halopriming imparts tolerance to salt and PEG induced drought stress in sugarcane. *Agriculture, Ecosystems and Environment*, *134*, 24–28. https://doi.org/10.1016/j.agee.2009.07.003

[67]. Saha, P., Chatterjee, P., & Biswas, A. K. (2010). NaCl pretreatment alleviates salt stress by enhancement of antioxidant defense system and osmolyte accumulation in mungbean (Vigna radiata L . Wilczek). *Indian Journal of Experimental Biology*, *48*, 593–600.

[68]. Sarkar, P. K., Kumar, P. R., Singh, A. K., & Bhatt, B. P. (2018). Effect of priming treatments on seed germination and seedling growth in bamboo [Dendrocalamus strictus (Roxb .) Nees]. *Acta Ecologica Sinica*, (xxxx). https://doi.org/10.1016/j.chnaes.2018.11.004

[69]. Schwember, A. R., & Bradford, K. J. (2005). Drying Rates following Priming Affect Temperature Sensitivity of Germination and Longevity of Lettuce Seeds. *Horticultural Science*, *40*(3), 778–781.

[70]. Sedghi, M., Nemati, A., & Esmaielpour, B. (2010). Effect of seed priming on germination and seedling growth of two medicinal plants under salinity دمحم يقدص ، يلع يتامن ، زورهبو ليعامسا روپ Introduction facing the farmers in developing countries was conducted at the University of, *22*(2), 130–139.

[71]. Sen, S. K., & Mandal, P. (2016). Solid matrix priming with chitosan enhances seed germination and seedling invigoration in mung bean under salinity stress. *Journal of Central European Agriculture*, *17*(3), 749–762. https://doi.org/10.5513/JCEA01/17.3.1773

[72]. Shafi, M., Bakht, Æ. J., & Zhang, G. (2009). Effect of Cadmium and Salinity Stresses on Growth and Antioxidant Enzyme Activities of Wheat (Triticum aestivum L .). *Bulletin of Environ Toxicol*, *82*, 772–776. https://doi.org/10.1007/s00128-009-9707-7

[73]. Sharma, A. D., Rathore, S. V. S., Srinivasan, K., & Tyagi, R. K. (2014). Comparison of various seed priming methods for seed germination , seedling vigour and fruit yield in okra (*Abelmoschus esculentus* L . Moench). *Scientia Horticulturae*, *165*, 75–81. https://doi.org/10.1016/j.scienta.2013.10.044

[74]. Shine, M. B., Guruprasad, K. N., & Anand, A. (2011). Enhancement of Germination , Growth , and Photosynthesis in Soybean by Pre-Treatment of SeedsWith Magnetic Field. *Bioelectromagetics*, *32*, 474–484. https://doi.org/10.1002/bem.20656

[75]. Singh, V., Upadhyay, R. S., Sarma, B. K., & Singh, H. B. (2016). Seed bio-priming with Trichoderma asperellum effectively modulate plant growth promotion in pea. *International Journal of Agriculture, Environment and Biotechnology*, *9*(3), 361–365. https://doi.org/10.5958/2230-732X.2016.00047.4

[76]. Sivakumat, T., Ambika, S. & Balakrishnan, K. (2016). Biopriming of rice seed with phosphobacteria for germination and vigour. *International Journal of Science and Nature*, *7*(3), 566–568.

[77]. Srivastava, A.K., Lokhande, V. H., Patade, V. Y., Suprasanna, P., Sjahril. R. & D'Souza, S.F. (2010a) Comparative evaluation of hydro-, chemo-, and hormonal priming methods for imparting salt and PEG stress tolerance in Indian mustard (Brassica juncea L.). *Acta Physiol Plant*, 32, 1135–1144.

[78]. Srivastava, A. K., Suprasanna, P., Srivastava, S. & D'Souza, S. F. (2010b) Thiourea mediated regulation in the expression profile of aquaporins and its impact on water homeostasis under salinity stress in Brassica juncea roots. *Plant Sci.* 178, 517–522.

[79]. Su, J., Hirji, R., Zhang, L., He, C., Selvaraj, G., & Wu, R. (2006). Evaluation of the stress-inducible production of choline oxidase in transgenic rice as a strategy for producing the stress-protectant glycine betaine. *Journal of Experimental Botany*, *57*(5), 1129–1135. https://doi.org/10.1093/jxb/erj133

[80]. Tavili, A., Zare, S. & Enayati, A. (2010). Hydropriming, Ascorbic and salicylic acid Influence on Germination of Agropyron elongatum Host. Seeds Under Salt Stress. *Research Journal of Seed Science*, *3*(4), 249–255.

[81]. Thomas, S., Anand, A., & Chinnusamy, V. (2013). Magnetopriming circumvents the effect of salinity stress on germination in chickpea seeds. *Acta Physiol Plant*, *35*, 3401–3411. https://doi.org/10.1007/s11738-013-1375-x

[82]. Van Hulten, M., Pelser, M., van Loon L. C., Corne´ M. J., Pieterse, and J. T. (2006). Costs and benefits of priming for defense in Arabidopsis. In *Proceedings of the National Academy of Science USA*. https://doi.org/10.1073/pnas.0510213103

[83]. Vashisth, A., & Nagarajan, S. (2010). Effect on germination and early growth characteristics in sunflower (Helianthus annuus) seeds exposed to static magnetic field. *Journal of Plant Physiology*, *167*(2), 149–156. https://doi.org/10.1016/j.jplph.2009.08.011

[84]. Vickers, C. E., Gershenzon, J., Lerdau, M. T., & Loreto, F. (2009). PERSPECTIVE A unified mechanism of action for volatile isoprenoids in plant abiotic stress. *Nature Chemical Biology*, *5*(5), 283–291. https://doi.org/10.1038/nchembio.158

[85]. Wahid, A., Perveen, M., Gelani, S., & Basra, S. M. A. (2007). Pretreatment of seed with H 2 O 2 improves salt tolerance of wheat seedlings by alleviation of oxidative damage and expression of stress proteins, *164*. https://doi.org/10.1016/j.jplph.2006.01.005

[86]. Wang, W., Chen, Q., Hussain, S., Mei, J., Dong, H., Peng, S., … Nie, L. (2016). Pre-sowing Seed Treatments in Direct-seeded Early Rice: Consequences for Emergence, Seedling Growth and Associated Metabolic Events under Chilling Stress. *Scientific Reports*, *6*, 1–10. https://doi.org/10.1038/srep19637

[87]. Watts, J. C. (2001). *The Effect of Seed Priming on the Germination, Emergence and Development of Five Different Grass Species*. University of Manitoba, Winnipeg, Manitoba.

[88]. Xu, S., Hu, J., & Li, Y. (2011). Chilling tolerance in Nicotiana tabacum induced by seed priming with putrescine. *Plant Growth Regulation*, *63*, 279–290. https://doi.org/10.1007/s10725-010-9528-z

[89]. Yadav, R. K., Saini, P. K., Pratap, M., & Tripathi, S. K. (2018). Techniques of seed priming in field crops. *International Journal of Chemical Studies*, *6*(3), 1588–1594.

[90]. Yan, M. (2015). Seed priming stimulate germination and early seedling growth of Chinese cabbage under drought stress. *South African Journal of Botany*, *99*, 88–92. https://doi.org/10.1016/J.SAJB.2015.03.195

[91]. Yousof, F. I. (2013). EFFECT OF RICE SEED PRIMING WITH CALCIUM CHLORIDE (CaCl 2) ON GERMINATION AND SEEDLINGS VIGOR UNDER SALINITY STRESS. *Plant Production*, *4*(4), 523–535.

[92]. Yuan-yuan, S. U. N., Yong-jian, S. U. N., Ming-tian, W., Xu-yi, L. I., Xiang, G. U. O., & Rong, H. U. (2010). Effects of Seed Priming on Germination and Seedling Growth Under Water Stress in Rice. *ACTA AGRONOMICA SINICA*, *36*(11), 1931–1940. https://doi.org/10.1016/S1875-2780(09)60085-7

[93]. Zhan, L., Peng, D., Wang, X., Kong, L., Peng, H., Liu, S., … Huang, W. (2018). Priming effect of root-applied silicon on the enhancement of induced resistance to the root-knot nematode Meloidogyne graminicola in rice. *BMC Plant Biology*, 1–12.

[94]. Zhao, T., Liu, Y., Yan, Y., Feng, F., Liu, W., & Zhou, H. (2007). Identification of the amino acids crucial for the activities of drought responsive element binding factors (DREBs) of Brassica napus. *FEBS Letters*, *581*, 3044–3050. https://doi.org/10.1016/j.febslet.2007.05.067