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Seed Priming to Improve Tomato Productivity in Salinity Stressed Environments: A Review

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Tomato (Solanum lycopersicum L.) berries are in great demand across the globe for their nutritive and therapeutic properties. As agriculture land and fresh water resources are limited, the possibility of increasing the production of tomato is either by utilizing unproductive salt affected land for cultivation or unportable water high in salts for irrigation. Tomato is relatively susceptible to salinity during seed germination and seedling establishment phase. However, rapid and synchronized seed germination is essential for proper stand establishment in tomato for increasing its production in salinity stressed environments. Seed priming, a simple and lucrative approach for easing salt stress during the germination phase, is gaining popularity in tomato. Priming improves germination response and brings about certain biochemical changes that help primed tomato seeds to survive and grow under harsh conditions of salinity. This review discusses some of the seed priming methods such as hydropriming, osmopriming, solid matrix priming, hormonal priming, chemical priming, biopriming and physical priming that successfully mitigated the harmful effects of salt stress in tomatoes. Seed priming thus paves the way for utilization of saline land for growing tomato resulting in increased productivity and an improvement in tomato supply chain amidst rising demands.

Keywords: Germination; Tomato; Salt stress; Seed priming.

Tomato (*Solanum lycopersicum* L.) placed in family Solanaceae is one of the most widely cultivated vegetables across the globe. Tomato berries are nutraceuticaly important because of the presence of diverse phytochemicals such as vitamin C, lycopene, beta-carotene, flavonoids and hydroxycinnamic acid derivatives making them an indispensable component of our daily diet. There is a major surge for tomato berries due to the presence of lycopene, a fat-soluble pigment valued for its anti-oxidant and anti-cancer properties [1]. To meet the growing demands, cultivation of this important vegetable needs to be enhanced. Currently, tomato is cultivated in 50 Lakh hectare land world-wide out of which nearly 8.12 Lakh hectare is under cultivation in India (FAOSTAT 2020). With limited agrarian land and paucity of fresh water resources, the possibility of increasing the production of tomato is either by utilizing unproductive or salt affected land for its cultivation or unportable water generally high in dissolved salts for irrigation [2]. Tomato is relatively susceptible to salinity during seed germination and seedling establishment phase. The commercial production of tomato is done by sowing seeds directly in the field rather than transplanting [3].

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Saline habitats increase the time required for germination and lower the germination percentage in tomato [4,5]. However, rapid and synchronized seed germination is essential in tomato for proper stand establishment and increasing its production in salt stressed environments. Presently, seed priming is becoming a lucrative method for alleviating salinity stress in tomato during germination which happens to be the most susceptible stage in the life cycle of this plant [6]. Priming permits certain pre germinative physiological and biochemical changes to occur without radicle emergence form the seed coat [7,8] supporting better growth and development of primed seeds in environmentally challenged conditions [9]. Seed priming was beneficial for successful adaptation of tomato and numerous other crops in presence of salt stress as reported earlier [6, 10-13]. This review focuses on different seed priming methods that were effective in tomato for mitigating salt stress and improving its productivity in salinity stressed habitats.

Salinity and Priming Methods

The priming methods which successfully counteracted the harmful effects of salinity stress in tomato (Table 1) by improving the germination and growth parameters are being discussed below.

Hydropriming

Hydropriming is a traditional method of soaking seeds in water with or without aeration followed by drying to original moisture content prior to sowing. It is important to standardize the soaking conditions such as duration, temperature and seed to water ratio for uniform hydration and germination [14]. Hydropriming is a simple, cost-effective and environmentally safe method[15]. Hydroprimed seeds of tomato exhibited better germination percentage and adjusted well in saline conditions [16].

Osmopriming

In osmopriming seeds are immersed in osmotic solution of low water potential for gradual and controlled imbibition preferably under aeration and dried to initial weight before sowing. Generally, osmolytes such as polyethylene glycol (PEG), sugar alcohols (mannitol, sorbitol), glycerol are utilized in osmopriming [17]. Priming treatments using osmotic solutions are effective compared to hydropriming as they permit gradual entry of water within the seeds reducing accumulation of reactive oxygen species and preventing oxidative injury [18]. Osmopriming with PEG increased the germination percentage and plant height [19]. It also lowered lipid peroxidation, relative electrolyte leakage and malondialdehyde levels [20] which helped in improving the tolerance of tomato towards salt stress.

When inorganic salt solutions of sodium chloride, potassium chloride, calcium chloride, magnesium nitrate, copper sulphate, zinc sulphate etc. are used as osmotic agents for priming individually or in combinations it is known as halopriming [21]. Priming with sodium chloride at seed sowing rather than post-emergence (4-leaf stage) helped in enhancing the yield in presence of salt stress [22]. Positive effects of halopriming such as early emergence, enhanced germination and seedling vigor under NaCl mediated abiotic stress is documented in tomato[8,23-27]. Biochemical parameters such as chlorophyll, sugar, proteins, antioxidant enzymes remained less impacted in primed seeds as compared to non-primed seeds[28,29]. Halopriming is a promising method to alleviate the effect of salt stress in tomato resulting in better germination parameters and biochemical functions.

Solid Matrix Priming

Seeds are incubated with solid matrices of inorganic or organic origin that serve as water carrier permitting slow and controlled hydration akin to seed imbibition in nature[30]. It is performed in a sealed container that allows air circulation but prevents evaporation. Post priming seeds are separated from solid matrix, washed and dried. The materials used for solid matrix priming should have high water holding capacity, less bulk density and low osmotic potential [15]. Some of the naturally occurring solid matrices used for priming include calcium silicate, calcined clay, vermiculite, cocopeat, perlite [31], sand, charcoal, sawdust, compost, press mud [32], *Sphagnum* moss, Wheat bran etc. [33] Solid matrix priming is cost-effective substitute to osmopriming as it avoids handling large volumes of osmotic solutions or maintenance of temperature and aeration [34]. Solid matrix priming with sand particles improved the germination parameters, seedling height, antioxidant enzymes and reduced malondialdehyde content in tomato in presence of salinity stress [35].

Hormonal Priming

Plant growth regulators or phytohormones are organic compounds synthesized in small

Table 1. Priming methods implemented in tomato for mitigating salinity stress

Method	Agent/Dose/ Duration	Experiment System	Range of NaCl Stress	Main Findings	References
Halopriming	NaCl/0.5,1.0 M		35, 70, 140 mM	Increased yield (1.0 mM NaCl), K/Na ratio; reduced shoot Cl^- & Na^+ ions.	Cano *et al.* (1991)
Halopriming	NaCl/6M/3 days	Silica sand	70, 140 mM	Early emergence, less reduction of shoot / root dry weight, accumulation of Na^+ & Cl^- ions in roots, increment in sugars, organic acids in leaves.	Cayuela *et al.* (1996)
Hydropriming; Halopriming; Hormonal Priming; Chemical Priming	Distilled water; $CaCl_2$/ 50mM; KNO_3/3%; NaCl/18 dm^{-1}; KH_2PO_4/0.5%; Kinetin/25 ppm; Salicylic acid/ 50 ppm; Ascorbic acid/ 50 ppm; H_2O_2/1%; Mannitol/2%/2hrs. to 6 days	in trays	150 mM	Kinetin lowered lipid peroxidation & hydrogen peroxide levels.	Theerakulpisut *et al.* (2011)
Hormonal Priming; Chemical Priming	Salicylic acid/ 50, 100, 150 mg/l; Ascorbic acid/50, 100, 150 mg/l/24 hrs.; H_2O_2/40, 80, 120 µM/8 hrs.	Moist Filter Paper	10 ds/m	Ascorbic acid & salicylic acid (150 mg/l) enhanced seed vigor. Hydrogen peroxide inhibitory at higher levels	Ghoohestani *et al.* (2012)
Solid Matrix Priming	Sand particles - 0.5 mm to 2 mm/ 4 % v/w/72 hrs.	Moist Filter Paper	50, 100, 150 mM	Increased germination percentage, root/shoot length, seedling vigour & antioxidant enzymes; reduced malondialdehyde content.	Nawaz *et al.* (2012)
Osmopriming	PEG/10%/2 days		100 mM	Enhanced seed vigor;	Zhang *et al.*

				reduced lipid peroxidation, relative electrolyte leakage & malondialdehyde levels.	(2012)
Halopriming	NaCl/5M/3 days	Pot Experiment in soil	100 mM200 mM	Increment in chlorophyll, Na^+, K^+, Ca^{+2}, Mg^{+2}, sugar in leaves.	Demirkaya (2014)
Halopriming graded	$CaCl_2/KNO_3$ Ebrahimi *et al.*	Germination	50,100,150 mM		Potassium nitrate up-
		Paper		germination index (50 mM stress).	(2014)
Halopriming	NaCl/0.05M	Pot Experiment	0.1, 0.2, 0.4, 0.6M	Increased germination percentage, seedling vigor, proline & anthocyanin. Chlorophyll, chlorophyll to carotenoid ratio, lipid peroxidation & electrolyte leakage less impacted.	Iseri *et al.* (2014)
Hydropriming; Osmopriming	Distilled water; PEG 6000/ -0.5, -1.0, -1.5, -2.0 MPa /48 hrs.	Pot Experiment in soil	4, 8, 12 dS/m	Increment in germination percentage, plant height & dry weight on osmopriming (PEG-0.5 MPa).	Pradhan *et al.* (2015)
Halopriming; Hormonal Priming	KCl/1%; $CaCl_2$/0.5%; IAA/100ppm; GA/ 1mM/BAP/50ppm; Salicylic acid/2mM; Ascorbic acid/100ppm	*In vitro* experiment	60 mM	Gibberellic acid improved germination percentage, stress tolerance index & alpha amylase activity.	Nandhitha *et al.* (2016)
Chemical Priming	Tryptophan/ 5mM; Proline/ 5mM; Arginine/5mM/ 4hrs.	Moist Filter Paper	30 mM &60 mM	Proline up-graded germination percentage, radicle length & seedling dry weight.	Hojagan *et al.* (2017)
Hydropriming; Chemical Priming	Distilled water; Proline/5mM/72 hrs.	*In vitro* experiment	40, 60, 80, 100 mM	Increased germination percentage, shoot/ root length of seedlings. Hydropriming effective to chemical priming.	Seth (2017)
Halopriming	KNO_3/1, 2, 3% /24 &48 hrs.	Cocopeat, perlite and vermiculite (3:1:1) in trays	2.5 & 5.0 dS/m	KNO_3 (1%, 24 hrs. & 2%, 48 hrs.) improved germination rate index, protein, chlorophyll & catalase.	Vaktabhai and Kumar (2017)
Hormonal Priming; Chemical	Salicylic acid/ 0.5, 1mM; H_2O_2/20, 50 mM			Salicylic acid (1mM) & hydrogen peroxide (50 mM) enhanced total soluble sugars,	Gaba *et al.* (2018)

Priming				proteins, antioxidant enzymes.	
Hydropriming; Halopriming	Distilled water /24 hrs.; NaCl/50 mM/ 24 hrs.; KNO_3/ 200 mM/8 hrs.	Pot Experiment in soil	8 dS/m	NaCl improved growth, yield & quality.	Biswas *et al.* (2019)
Halopriming; Chemical Priming	$CaCl_2$/50 mM; NaCl/50 mM; KNO_3 /50 mM; Menadion sodium bisulfite/30 mM, Chitosan/0.6, 0.4%		2.2, 4.0, 8.0 dS/m	Calcium chloride (50 mM) improved dry weight of stem/root.	Niazi and Sharifi (2019)
Halopriming	NaCl/85 mM	Hydroponic	85 mM	Better osmotic adjustment & quantum yield of photosystem II. Decline in leaf solute potential, transpiration rates & stomatal conductance.	Gonzalez-Grande *et al.* (2020)
Hormonal Priming (2021)	Ascorbic acid/100 mM	Culture	100 mM	Increment in water potential, water use efficiency, total pigments, antioxidant enzymes; reduced lipid peroxidation, Na^+ & H_2O_2 level.	Alves *et al.*
Biopriming	*Ulva lactuca* methanol extract and its fractions /1 mg/ml/24 hrs.	Sand: Peat in trays	2, 4, 8 dS/m	Increment in fresh weight, total proteins, sugars, chlorophyll; decline in hydrogen peroxide and antioxidant activity.	El Boukhari *et al* (2021)
Chemical Priming; Hormonal Priming	Proline/5,10 mM; Ascorbic acid/1, 4 mM/2hrs.	Moist Germination Paper	25, 50, 75 mM	Increased germination percentage, total soluble sugars, total soluble proteins, antioxidant enzymes, Proline (10 mM) and Ascorbic acid (4 mM) effective.	Kaur *et al.* (2021)
Biopriming	*Bacillus paralicheniformis* Undiluted & diluted bacterial suspension/ 1:1, 1:2, 1:3/12 hrs.	Moist Germination Paper and Roll Towel Paper	25, 50, 75 mM	Undiluted *Bacillus paralicheniformis* suspension improved germination percentage, shoot/root length, vigour index & dry matter.	Parinith *et al.* (2022)
Physical Priming Method	UV-C/0.85, 3.42 kJ/m^2	Hydroponic Culture	100 mM	Improved seedling tolerance. Root biomass, root potassium supply & leaf protein (0.85 kJ/m^2 UV-C); protein, total polyphenol & tannin content in roots (3.42 kJ/m^2 UV-C) comparable to control.	Alamer and Attia (2022)

amounts within the plants, that facilitate proper growth and development. There are nine phytohormone's namely auxin, cytokinin, gibberellin, abscisic acid, ethylene, jasmonic acid, salicylic acid, brassinosteroids and strigolactones [36]. Priming of seeds with phytohormones termed as hormonal priming is helpful in increasing the germination response under abiotic stress. Hormonal priming increases the enzymatic activity of amylases and proteases that help in breakdown of reserve food materials such as starch and protein for its mobilization to the embryo thus hastening the germination events [37]. Priming with plant growth regulators such as salicylic acid and jasmonic acid accelerate germination percentage and improve seedling establishment by maintaining the functions of auxins and cytokinins within the plant [38]. There are reports on hormonal priming with kinetin, gibberellin, salicylic acid and ascorbic acid in tomato [39-43]. Improvement in germination percentage and seed vigour was achieved on priming with ascorbic acid, salicylic acid[40] and gibberellic acid [41] in stressful conditions. Priming with kinetin [39] and ascorbic acid [43] reduced lipid peroxidation and hydrogen peroxide levels resulting in improved tolerance towards salt stress. The germination percentage and biochemical parameters enhanced on ascorbic acid treatment thus negating the effect of salinity on emergence and early seedling growth [44].

Chemical Priming

Seeds are soaked in natural or synthetic chemical agents for preparing them to withstand stress during emergence and early growth phases [45]. Chemical priming is emerging as an effective method for handling abiotic stress [46]. Several chemicals are employed as priming agents such as amino acids [16,44,47], hydrogen peroxide [42], hydrogen sulphide, nitric oxide, chitosan, menadione sodium bisulfite [27], selenium, ethanol, putrescine, choline, butanolide, polyamines etc.[13,45] for stress management. Priming of tomato seeds with proline improved germination percentage, radicle length and seedling dry weight [47]. Accumulation of total soluble sugars, proteins and antioxidant enzymes in proline primed seeds helped them withstand salt stress [44].

Biopriming

Biostimulants are natural substances required in small amounts which help the plant by enhancing the nutrient uptake and utilization, improving availability of nutrients, increasing tolerance to abiotic stress and leading towards better crop quality and yield. Biostimulants comprise of various natural substances such as humic acid, fulvic acid, plant and animal protein hydrolysates, seaweed extracts, botanicals, chitosan, mycorrhiza, plant growth promoting rhizobacteria, inorganic compounds like silicon etc. [48] They can be applied to the seeds, plants or rhizosphere. Many biostimulants are being used as seed biopriming agents for better tolerance towards abiotic stress [49,50] amongst them sea weed extracts and *Bacillus paralicheniformis* suspension have shown promising response in ameliorating salt stress in tomato. Priming with *Bacillus paralicheniformis* suspension and *Ulva lactuca* methanol extract and its fractions increased the germination percentage and biomass accumulation [51,52].

Physical Priming Methods

Seed priming with physical agents presents a promising advancement compared to the usual water or chemical based methods [53]. Physical priming methods are less expensive and more environment friendly alternative to the traditional priming procedures. Some of the physical agents generally employed in seed invigoration are magnetic fields, electromagnetic waves (microwaves, infra-red rays, UV rays, X-rays, gamma rays), ultrasonic waves, cold plasma, laser beams and low energy electronic beams [53-55]. Physical priming agents showed improvement in seed germination rate, seedling vigour and better tolerance towards abiotic stress [56]. Improved germination response might be attributed to enhanced activities of hydrolysing enzymes, whereas better adaptability in stressed environments could be due to increased activity of antioxidant enzymes in response to physical priming agents. UV-C seed priming mitigated the effect of salt stress in tomato seedlings. Increment in antioxidant activities in UV-C primed seeds helped them to adapt well in presence of salinity stress [57].

CONCLUSION

With limited farming land and fresh water resources, the area under cultivation can be increased by utilizing unproductive or salt affected land and poor-quality water high in salts for agriculture purpose. Tomato is moderately sensitive to salinity during seed germination and early seedling stage. Some of the seed priming methods such as hydropriming, osmopriming, solid matrix priming, hormonal priming, chemical priming, biopriming and priming with physical agents were effective in coping with salt stress in tomato. Primed seeds of tomato presented better germination percentage, speed, vigor, uniformity as compared to unprimed seeds in presence of salinity stress. Priming treatments were effective in improving the biochemical parameters such as chlorophyll, total soluble sugars, proteins and antioxidant enzymes in tomato seedlings proving advantageous for sustainability in salt stressed conditions. Seed priming is simple and profitable technique that farmers can easily implement during tomato cultivation. Primed tomato seeds will be better equipped for tolerating salt stress that happens to be a persistent problem in changing climatic conditions and is one of the major threats to global food security.

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Conflict of Interest

Author declares no conflict of interest.

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