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Biostimulatory Impacts of Seed Priming through Botanical Extracts on Crop Production: A Critical Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Rapid human population increase, food scarcity, and climate change are some of the global challenges in the current scenario. Among these, climate change adversely impacts crop production by creating abiotic stresses such as drought, salinity, and metal toxicity. Seed emergence, the critical stage in crop development, is highly vulnerable to these abiotic stresses. Therefore, short-term approaches to increase seed germination and the initial growth of plants were investigated in advance as a solution. Seed priming is indeed a pre-sowing treatment of seeds. It is a technique used to enhance the germination and early growth of seeds by exposing them to controlled hydration and sometimes other treatments before planting. Seed priming considered a low-cost, eco-friendly, and sustainable technique to promote seed germination and the initial growth of plants. Though various priming methods are available, this review discusses only botanical extracts (both seaweed and plant extracts) used as priming agents in seed priming. Among the seaweed extracts, green and brown algae species such as *Ascophyllum nodosum, Sargassum spp.,* and *Ulva spp.* enhanced the crop performances even under stress conditions. In addition, leaf

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extracts derived from drumstick (*Moringa oleifera)* and neem (*Azadirachta indica)* are widely used to increase the crop production under stress and non-stress environments. Furthermore, in this review discussed about priming mechanism, different extraction methods and bioextracts behavior under diverse agroecosystems are discussed in detail.

Keywords: Abiotic stresses; antioxidant; bioextracts; biostimulant; seed priming.

1. INTRODUCTION

The challenge of a rising population affects the world. Due to population expansion, more individuals would require assistance with food security and supply. However, climate change, environmental pollution and abiotic stressors significantly impact on seed germination, emergence, seedling vigour, and crop production [1]. These undesirable impacts on crop production and performance of significantly influence the food and agricultural systems. Several approaches, such as conventional breeding and advanced technologies (e.g., genetic engineering, mutation breeding, and polyploidy breeding) are being assessed to enhance crop production under environmental challenges. However, these techniques have significant drawbacks, including sizeable human resource requirements, biosafety apprehensions, and ethical concerns [1]. Thus, it is necessary to develop simple, efficient, and sustainable technology to solve these issues [2]. In this regard, seed priming is an alternative approach to getting around these constraints and increasing the capacity of plants to withstand stress [3,4].

Seed priming is a simple and an efficient method that would enhance plant's physiological and biochemical responses to abiotic stresses; thus, regulates hydration of seeds that permits pre-germination of metabolic activities without causing the radicle to emerge [5]. Basically, seed priming improves the seed germination or seedling growth rate through entrusting uniformity of seedling establishment [6]. Besides, priming process ensures early emergence, efficient water usage, mitigation of excessive fertilizer usage, promote roots growth, initiate the growth of reproductive organs, early flowering and maturity, resistance to abiotic stresses and soil-borne pathogens [2,6]. According to the way of conducting priming procedure, seed priming methods can be classified as hydro-priming, halo-priming/chemo-priming, osmo-priming, osmo-hardening, on-farm priming, matrix priming, nutri-priming, nano-priming, bio-priming, thermo-priming, UV priming and hormone priming [2,7]. Hydro-priming is achieved by soaking seeds in clean water and re-drying them to their initial moisture content before planting [8]. In this regard, hydro-priming shortens the lag phase of the germination process and facilitates rapid germination for vigorous development [9,10]. In osmo-priming, a low water potential osmotic solution is used to soak seeds rather than pure water [1]. Numerous materials are used in osmo-priming, including mannitol, sorbitol, glycerol, and inorganic salts [7].

Osmo-hardening includes re-drying of seeds after soaking them in tap water for 24 hours, then hardening them with Calcium chloride and Potassium chloride solutions [2]. In solid matrix priming a solid or semi-solid media is employed instead of a liquid medium. This method involves combining seeds with a solid or semi-solid substrate with certain quantity of water [9]. Solid matrix priming would regulate water absorption by properly adjusting of moisture content [7]. In nutrient priming, seeds are exposed to a particular concentration of macro or micronutrients for a predetermined duration before planting. One of the novel seed priming techniques is nano-priming which uses nanoparticles (NPs), such as zinc oxide, iron oxide, titanium dioxide, silver nano-particles etc. [2]. In bio-priming, specific microorganisms or bioactive molecules are used for seed treatment [7]. Thermo-priming involves treating seeds at various temperatures while minimizing the influence on their critical physiological functions [7]. In hormonal priming, plant growth regulators like auxins, gibberellins, kinetin, salicylic acid, abscisic acid, ethylene, and ascorbic acids are widely utilized to enhance the plant growth [9]. Apart from these methods, in chemical priming seeds are treated with either organic (e.g., organic acids, botanical extracts, chitosan, polyamines, mannose, and trehalose) or inorganic (e.g., sodium nitroprusside, and sodium hypochlorite) substances [11].

2. SEAWEED EXTRACTS USED IN SEED PRIMING

Seaweed, often known as marine macroalgae, comprises a large portion of the world's marine life resources [12]. Most of their distribution recorded in shallow coastal waters, estuaries, and backwaters; but relatively small quantity has been found on solid surfaces like rocks, dead coral, and pebbles [12]. Approximately 10,000 species of macroalgae exist in globally which account for 10% of marine productivity [13]. According to presence of pigments, marine macroalgae would divide into three categories namely; (a) Chlorophyta or green algae, (b) Rhodophyta or red algae, and (c) Phaeophyta or brown algae respectively [14]. Brown algae mainly encompasses chlorophyll a and c with carotenoids and fucoxanthin while green algae contain pigments that are identical to the chlorophyll a, b and carotenoids which found in terrestrial plants [14]. Red algae contains both chlorophyll a, b, and phycoerythrin pigment which is responsible for the color of the red algae [15, 16].

Seaweed extracts have been used as a seed treatment to improve the seed germination, crop growth and development [17]. These are widely recognized to include a number of bioactive compounds [18]. A variety of biologically active components including polyphenols (e.g., phenolic acids, flavonoids, cinnamic acid, isoflavones, benzoic acid, lignans, quercetin), polysaccharides (e.g., galactan, fucoidan, alginate, laminarin), proteins (e.g., lectins), polyamines, pigments, free amino acids, vitamins, micronutrients (e.g., B, Co, Cu, Fe, Mn, Mo, Ni, Si, Zn), macronutrients (e.g. Ca, K, Mg, Na, P, S), and natural phytohormones (e.g., cytokinins, auxins, gibberellins, abscisic acid), antioxidants, osmo-protectants betains, antimicrobial compounds are consist in seaweed extracts [16-19]. Furthermore, seaweeds have elicitor chemical precursors that aid for seed germination [20]. Several Seaweed extracts used for seed priming are summarized in Table 1.

The commercial Seaweed extracts sector employs various exclusive extraction methods to rupture the cells and release beneficial components into the extract. These extraction techniques are further classified as enzyme-assisted extraction, microwave-assisted extraction, pressurized liquid extraction, supercritical fluid extraction, ultrasound-assisted extraction, soxhlet extraction, alkali extraction, acid extraction, and cell bust extraction [13, 18, 19]. In this regard, a variety of solvents, including ethanol, acetone, methanol-toluene, methanol, petroleum ether, ethyl acetate, dichloromethane, and butanol can be utilized for an effective extraction process. However, these procedures are sometimes considered costly and hazardous [19]. Hence, boiling and soaking extraction techniques with distilled water are used to overcome conventional extraction techniques' drawbacks; which are eco-friendly and require no organic solvents [19].

3. PLANT EXTRACTS USE IN SEED PRIMING

Another effective method to promote germination is soak the seeds in plant extracts before planting [52]. Numerous chemical compounds identified in various plant species that improve the growth, development, and productivity of crops grown under adverse conditions. Plant extracts modify the physiological and biochemical processes such as stomatal conductance, phytohormone metabolism, absorption of water and nutrients, antioxidant defensive systems, and photosynthesis [53]. Different plant extracts used for seed priming are summarized in Table 2.

According to the literature, several Plant extracts are widely used in crop cultivation such as *Allium sativum* (Garlic), *Zingiber officinale* (Ginger), *Azadirachta indica* (Neem), *Codiaeum variegatum,* (Crouton), *Moringa oleifera* (Moringa/Drumstick), *Datura stramonium* (Jimsonweed), *Aloe vera* (Aloe), *Ricinus communis* (Castor), *Allium cepa* (Onion), *Helianthus annuus* (Sunflower), *Sorghum bicolor* (Sorghum) etc. [54,55,56,57,58). Plant extracts are rich in macro and micronutrients, antioxidants, amino acids (e.g., alanine, glycine, leucine and proline), ascorbate, zeatin, growth hormones, vitamins (e.g., B-complex, C, β-carotene, α-tocopherol), allelochemicals, enzymes (e.g., amylase, catalase, lipase, oxidase, superoxide dismutase) and other organic compounds (e.g., triglycerides, triterpenoid, gibberellin, potassium sorbate and salicylic acid) [52,53,59]. However, plant extracts would have a variety of compositions depending on the plant species.

Table 1. Seed priming through seaweed extract

No	Seaweed extract type	Crop	Priming condition	Impact of seed priming	Stress type	Country of study	Reference
1	*Ascophyllum nodosum*	Spinach	Seeds were soaked in solutions ranged from 0.15% to 1.2%	A concentration of 0.3% treatment showed the highest seed germination percentage.	Thermal stress	Brazil	[21]
		Moth bean	Seeds were soaked with various concentrations extended from 0.01% to 1.0% for different periods ranged from 0 to 24 hours	Improved the seed germination, shoot and root length, fresh and dry weight, free radical scavenging, whereas alpha-glucosidase inhibitory action at low concentrations	Non-stress	India	[14]
		Onion	Seeds were soaked for 6 hours in different concentrations extended from 0ppm to 7500ppm	Enhanced germination percentage, shoot length and root length at lower concentrations (5500ppm)	Non-stress	India	[22]
		Pepper	Seeds were primed for 1 to 3 days in an incubator at 20°C using concentrations ranged from 1:1 to 1:1000 dilutions of seaweed extract and water	Increased total seed germination rate and decreased the mean germination time at 1:500 concentration	Non-stress	Turkey	[23]
	Colpomenia sinuosa Sargassum vulgare	Fenugreek	Seeds were soaked for 12 hours with various concentrations extended from 5% to 25%	Enhanced the seed germination, biochemical constituents under low concentration	Non-stress	Egypt	[24]
	Codium taylorii Pterocladia capillacea	Radish	Sterilized seeds were soaked for 2 hours in water	Enhanced plant height significantly	Salinity Stress	Egypt	[25]
	Codium tomentosum	Wheat	Seeds were soaked in different concentrations extended from 10% to 50% at 12 hours	Increased seed germinating percentage, shoot length, root length, fresh and dry weights of seedlings at 20% concentration	Non-stress	Egypt	[26]
2	*Cystoseira compressa*	Cowpea/ Maize	Seeds were soaked in a concentration of 20 gL^{-1} seaweed solution for 2 hours	Increased the germination rate of both crops, vigorous coleoptile elongation of maize, increased biomass weight and guaiacol peroxidase activity	Salinity stress	Egypt	[27]
3	*Ecklonia maxima*	Okra	Seeds were immersed for 24 hours in Kelpak® solution under	Seed germination was increased in 1:100 solution	Non-stress	South Africa	[28]

No	Seaweed extract type	Crop	Priming condition	Impact of seed priming	Stress type	Country of study	Reference
			1:20, 1:40 and 1:100 v/v) levels				
		White foxglove	Seeds were treated with Kelpak® 0.4% concentration for 48 hours	Enhanced the seed germination and seedling growth	Heat stress	South Africa	[29]
		Maize	Soaked seeds in aqueous solution of seaweed extracts for 24 hours	Induced seed germination and shoot weight	Non-stress	Poland	[30]
4	*Ecklonia maxima Jania adhaerens*	Tomato	Seeds were immersed in concentrations of 2.5, 5.0, and 10.0 mg mL^{-1} overnight	10 mg mL^{-1} extraction exhibited highest seed emergence and plant dry weight	Non-stress	Italy	[31]
	Gracilaria textorii J. Agardh and *Hypnea musciformis* (Turner)	Brinjal, Chilly and Tomato	Seeds were soaked in the various ratios (1:2, 1:4, 1:6, 1:8, 1:10, 1:20,1:30) w/v% for 12 hours	Seaweed extraction (1:4, 1:6) increased seed germination and crop yield	Non-stress	India	[32]
5	*Gracilaria edulis*	Chilli	Seeds were primed with concentrations extended from 1:1 to 1:1000 (Seaweed extract: water) for 24 hours, 48 hours and 72 hours	Improved the seed germination, storability and higher fruit yield at 1:25 for 48 hours, 1:5 for 24 hours and 1:5 for 72 hours conditions	Non-stress	India	[33]
6	*Jania rubens*	Maize	Seeds were primed for seaweed concentration 10% w/v)	Significantly enhanced seed germination, seedling vigor and plant growth, as well as photosynthetic pigments	Non-stress	Morocco	[34]
7	*Kappaphycus alvarezii /Gracilaria edulis*	Rice	Seaweed extracts were added to rice seeds at concentrations of 2.5%, 5%, 7.5%, 10% and 15% for 24 hours	Rice seed germination and seedling vigor were increased at 2.5% and 5% concentrations	Non-stress	India	[35]
8	*Laurencia obtusa*	Cowpea/ Maize	Seeds were soaked in 20gL^{-1} concentrated seaweed extract for 2 hours at 25 °C	Increased the germination rate, coleoptile elongation, biomass weight	Salinity stress	Egypt	[27]
	Padina gymnospora	Tomato	Seeds were treated with different concentrations (0.2, 0.4 and 1.0 % w/v) for 24 hours	Seaweed concentration with 2% enhanced germination, rate of germination, germination index, greater seedling vigor, plumule and radicle length	Non-stress	Mexico	[36]
9	*Solieria spp.*	Kale	Seeds were soaked in 0.25, 0.5,	Seed primed with seaweed extract has not	Non-stress	Brazil	[37]

No	Seaweed extract type	Crop	Priming condition	Impact of seed priming	Stress type	Country of study	Reference
			and 1.0 ml L^{-1} 22 hours at 20°C	interfered with seed health			
	Sargassum polycystum	Red gram	Seeds were treated with different concentrations of water extracted and alcohol extracted seaweed (0.1, 0.25, 0.50, 0.75, 1.0 and 1. 5% w/v) for 12 hours	The lowest concentration showed higher seed germination, shoot length, root length, fresh weight and dry weight	Non-stress	India	[38]
	Sargassum tenerrimum	Tomato	Seeds were immersed in a variety seaweed aqueous extract concentrations of 0.2%, 0.4%, 0.6%, 0.8%, and 1.0% w/v	Seed germination rate was increased at 0.8%	Non-stress	India	[39]
	Sargassum vulgare	Wheat	Seeds were soaked in different concentrations ranged from 10% to 50% w/v for 12 hours	Increased seed germination, growth and yield in 20% concentrated treatment	Non-stress	Egypt	[26]
		Tomato	Seeds were treated with 0.2% and 0.5% concentration of seaweed extract and then exposed for 14 days photoperiod	Seaweed concentration of 0.2% enhanced seed germination and the growth of the radicle	Salt stress	Morocco	[40]
		Wheat	Seeds were treated at different concentrations (0.2, 0.5, 25 and 50 % w/v) and kept under photoperiod for 14 days	The lowest concentrated treatment enhanced the germination rate with lower mean germination time and showed greater seedling vigor	Salt stress	Tunisia	[41]
	Sargassum vulgare, Colpomenia sinuosa, Pandia pavonica	Pea	Water extract of 10 g/L concentrated seaweed extracts primed for 2 hours	Increased the production of photosynthetic pigments, new peptides, and improved germination, seedling length, and fresh weight	Salt stress	Egypt	[42]
	Sargassum wightii Grev.	Green gram	Seeds were soaked with seaweed concentrations of 0.5%, 1.0%, and 2.0% w/v for three-time intervals (6,12 and 24 hours)	Seed soaked in 0.5% concentrated seaweed extract for 6 hours led to higher seed germination and earlier growth	Non-stress	India	[43]
	Sargassum wightii	Wheat	Seeds were soaked with different concentrations ranged from 5% to 50% for 12 hours	Seaweed concentrated with 20% increased the germination rate, number of lateral roots, shoot length, number of kernels per plant, and kernel length	Non-stress	India	[44]

No	Seaweed extract type	Crop	Priming condition	Impact of seed priming	Stress type	Country of study	Reference
	Thalassia hemprichii	Green gram	Seeds were treated with 50 ppm and 100 ppm of seagrass extract	In comparison to the control treatment, the root: shoot ratio has risen for all of the treatments	Non-stress	India	[45]
	Ulva, Polysiphonia,	Garden cress	Seeds were treated with concentration of 0.5, 2.5 and 10%	Chlorophyll content was higher in 0.5% concentrated Garden cress plants	Non-stress	Poland	[19]
	Ulva fasciata *Padina gymnospora* *Gracilaria edulis*	Bell pepper	Seeds were soaked in seaweed extract at various concentrations (2, 4, 6, 8 and 10%) w/v for 24 hours	The phytochemical content and germination were enhanced at 8% concentrated *Padina gymnospora*	Non-stress	India	[46]
12	*Ulva fasciata,* *Padina gymnospora,* *Gracilaria edulis*	Chilli	Seeds were treated in various concentrations of seaweeds extracts ranged from 2% to 10% for 24 hours	Phytochemical content and germination were enhanced by *Padina gymnospora* at 8% concentration level	Non-stress	India	[15]
13	*Ulva lactuca*	Onions	Solid matrix priming using a 2:1:3 (weight basis) mixture of seed, vermiculite, and seaweed extract were carried out at 15 °C for 2 days, seaweed extract was applied at 5% concentration	Enhanced the seed germination and seedling quality	Drought and salinity stresses	N/A	[47]
		Carrot	Solid matrix priming using a 2:1:3 (weight basis) mixture of seed, vermiculite, and seaweed extract	Enhanced the germination fresh and dry weight of seedling	Salinity stress	Turkey	[48]
		Tomato	Seeds were soaked for 24 hours at 25°C in a 1 $mgmL^{-1}$ solution	Increased the tomato fresh weight, glycine betaine, total phenols and soluble sugars concentration, significantly decreased the hydrogen peroxide concentration	Salinity stress	Morocco	[49]
		Cowpea and Maize	Seeds were soaked for 2 hours at 25 °C in a concentration of 20 gL^{-1}	Observed higher germination rate of both crops, vigorous coleoptile elongation of maize, increased biomass weight and guaiacol peroxidase activity	Salinity stress	Egypt	[27]
		Tomato	Seeds were soaked in 0.2, 0.4, and 1.0% concentrated solution for 24 hours	0.2% concentrated priming treatment enhanced germination, rate of germination, lower mean germination time, high germination index, greater seedling vigor, greater plumule, radicle length	Non-stress	Mexico	[36]

No	Seaweed extract type	Crop	Priming condition	Impact of seed priming	Stress type	Country of study	Reference
	Caulerpa scalpelliformis *Turbinaria conoides* *Padina Tetrastromatica*	Green gram	Seeds were soaked for 12 hours with concentrations ranged from 0.1% to 0.5% w/v seaweed extracts	The 0.3% concentration has the lowest germination percentage and maximum germination (100%) has 0.4% *Caulerpa scalpelliformis* and 0.1% *Padina tetrastromatica* extractions	Non-stress	India	[50]
14	*Ulva linza* *Corallina officinalis*	Wheat	Seeds were soaked for 12 hours in aqueous extract at different concentrations ranged from 5% to 30% w/v	Increased the seedling growth and germination at 8% concentration	Non-stress	Egypt	[51]

Table 2. Seed priming through plant extracts

No	Plant extract type	Crop	Priming condition	Impact of seed priming	Stress type	Country of study	Reference
1	Moringa leaf extract	Maize	Seeds were soaked at the ratio of 1:10 w/v concentrate for 12 to 20 hours	Improved the germination and seedling growth	Non-stress	Egypt	[52]
		Rice	Seeds were soaked in an aerated solution of moringa leaf extract at 3% for 8 hours	Improved the speed and spread of emergence of seedlings (e.g., Time to start emergence, emergence index, mean emergence time, final emergence percentage)	Drought stress	Pakistan	[53]
			Seeds were soaked in the moringa leaf extract (seed weight: moringa leaf extract 1:5) at room temperature in dark conditions under continuous shaking for 24 hours	Improved seed germination and plant growth	Arsenic stress	India	[58]
		Onion	Seeds were soaked in 12.5% and 25% of moringa leaf extract 6 and 12 hours respectively	Seeds soaked for six hours and 12.5% concentration had the highest percentage of emergence	Non-stress	Nigeria	[60]
		Wheat		Improved seed germination and seedling growth	Salinity stress	Libya	[61]

No	Plant extract type	Crop	Priming condition	Impact of seed priming	Stress type	Country of study	Reference
			Seeds were soaked in moringa leaf extract 1:10 concentration for 12 hours				
		Raddish	Seeds soaked in 3% and 5% of moringa leaf extract for 6 and 9 hours under continuous aeration	Increased growth with improved biochemical and antioxidant attributes at 3% concentration for 6 hours	Non-stress	Pakistan	[62]
		Cucumber	Aerated fresh moringa leaf extract for 18 hours	Improved germination and seedling growth	Non-stress	Nigeria	[63]
		Pea seeds	Seeds were primed with 3% moringa leaf extract and in combination of magnetized water and moringa leaf extract for 12 hours	Improved germination capacity and seedling vigor	Non-stress	Pakistan	[64]
		Cowpea	Primed with 5% and 2% concentrations of moringa leaf extract for 12 hours	Increase germination percentage with better root and shoot length at 5% concentration	Non-stress	Pakistan	[65]
		Linola	Seeds were primed with 3.3% concentration of moringa leaf extract for 12 hours	Improve crop growth and yield	Non-stress	Pakistan	[66]
		Sesame	Primed with 2%, 4% and 6% concentrations of fresh moringa leaf extract for 6 hours	Improved the seedling emergence and growth at low concentration (2%)	Non-stress	Pakistan	[67]
		Spring maize	Priming 3% moringa leaf extract for 18 hours	Increased root and shoot lengths, the ratio of root:shoot, length and maximum seedling fresh and dry weights	Cold stress	Pakistan	[68]
		Hybrid maize	Primed with 1:30(diluted to 30 with distilled water) and 1:40(diluted to 40 with distilled water) moringa leaf extract for 18 hours	Observed higher emergence rate and better early seedling growth in 1:30 concentration	Non-stress	Pakistan	[69]
2	Neem leaf extract	Bread Wheat	Seeds were soaked in 15ml/100ml water solution for	Enhanced plant growth and reduced nematode infestation	Non-stress	Pakistan	[57]

No	Plant extract type	Crop	Priming condition	Impact of seed priming	Stress type	Country of study	Reference
			12 hours				
		Rice	Seeds were primed with neem leaf extract concentrations 25%, 50% and 100% for 24, 48, and 72 hours	Increased the seed germination at 50% concentration for 24hours	Non-stress	Sri Lanka	[70]
		Chickpea	Seeds were primed in 5% and 10% neem leaf extract for 10 hours	10% concentrated solution significantly affected for the emergence percentage, primary branches per plant, pods/plant, seeds per pod, and seed yield per plant	Non-stress	India	[59]
		Lentil	Seeds were primed in 50% concentration of neem leaf extract solution for overnight	Observed higher germination percentage, number of branches per plant, seeds per pod, 1000 seeds weight, and yield	Non-stress	India	[55]
3	Garlic extract	Brinjal	Seeds were primed in 100, 200, and 300 µg mL^{-1} for 4, 8, and 12 hours respectively	Seed priming with 200 µg mL^{-1} of extract for 12 hours showed the maximum germination percentage	Non-stress	China	[54]
4	Sorghum water extract	Camelina	Seeds primed in 5% solution for 24 hours at 25 ℃	Increased the emergence percentage and ionic homeostasis. In addition, enhanced seedling growth, biomass production, and chlorophyll content	Salinity stress	Pakistan	[56]
		Sunflower/ Maize	Seeds were primed with concentrations extended from 1% to 3% for 8 hours and 14 hours	Seeds primed with 1 and 1.5% concentrations resulted in the highest root/shoot dry weight in maize and 2.5% concentrated treatment in sunflower	Non-stress	Pakistan	[71]
6	Arappu extract	Okra	Seeds were kept in 3% solution for 12 hours	Increased germination and seedling vigor	Non-stress	India	[72]
7	Sugar beet extract	Wheat	Seeds were primed at different concentrations (10%-50%) for 12 hours	Increased germination percentage, reduced the negative effects of water stress on seed germination and increased plant growth at 10% and 20% concentrations.	Water stress	Pakistan	[73]
	Eclipta alba	Sorghum	Seeds were soaked in 2.5% concentration of extract for 6	Increased the yield, emergence, and suppression of pathogenic fungi	Non-stress	Denmark	[74]

No	Plant extract type	Crop	Priming condition	Impact of seed priming	Stress type	Country of study	Reference
			hours				
	Prosopis (*Prosopis juliflora*)	Black gram	Seeds were soaked in leaf extracts at 1% solution for 4 hours	Enhanced the seed quality characters like germination percentage, speed of germination, root length, shoot length, seedling length, dry matter production, vigour index	Non-stress	India	[75]
		Pigeon pea	Seeds were primed with 2% leaf extract for one hour	Enhanced the seed and seedling quality characters	Non-stress	India	[76]
	Marigold	Pepper	Seeds were primed at 0.4% concentration at 25 °C for 24 hours in the dark	Increased seed germination, emergence and the seedling fresh weight at different maturity levels	Non-stress	Turkey	[77]
	White musale, Periwinkle, Neem, Wood apple, Lantana and White cedar	Tomato	Seeds soaked in 1%, 2% and 4% concentration for 4 hours at room temperature	Improved the seedling growth at 2% and 4% concentrations than 1%	Non-stress	India	[78]
	Acacia nilotica (L.) *and Sapindus mukorossi*.(L.)	Peanut, chickpea, sunflower and okra	Seeds were primed with 11% concentration of A. *nilotica* and S. *mukorossi* stem, leaf, and seed extracts at different time intervals (5, 10, 20, and 40 minutes)	Enhanced plant growth and controlled root rot fungus in seed priming with *A. nilotica* and *S. mukorossi* leaves extract for 10 minutes	Non-stress	Pakistan	[79]
	Cyperus esculentus (Della) *Axonopus compressus* (Itsit), *Convulvulus arvensis* (Lehli) and *Parthenium hysterophorus* (Parthenium)	Rice	Seeds were soaked in weed extract for 30 minutes with a seed weight to solution volume ratio of 1:5 (g mL^{-1}).	Increased germination rate and germination percentage	Non-stress	Pakistan	[80]
	Aloe vera, *Moringa olifera* or sugar beet aqueous extracts	Lentil	Seeds soaked for 14 hours using five concentration levels extended from 1% to 5%	Enhanced germination rate and seedling growth with priming of 2% aloe vera extract, 3% moringa leaf extract and 2% sugar beet aqueous extract respectively	Chilling stress	Pakistan	[81]
	pungam	Cluster	Seed soaked in 1% and 2%	Enhanced seed germination, vigour, and field	Non-stress	India	[82]

No	Plant extract type	Crop	Priming condition	Impact of seed priming	Stress type	Country of study	Reference
	(*Pongamia pinnata*) and arappu (*Albizia amara*)	bean	concentration for 3 hours and 6 hours respectively	emergence of seedlings at 2% concentration and 3 hours soaking			
9	*Cyperus rotundus L.*	Drumstick	Seeds were soaked in four aqueous extracts of *Cyperus rotundus* concentrations (0%, 25%, 50% and 100%)	Increased in initial shoots length and photosynthetic pigments accumulation in seed priming with 50% concentration	Non-stress	Brazil	[83]
10	Tomato leaf extract	Sugar beet	Seeds were primed in the extracts of the lower, middle, and upper leaves of six different tomato varieties for 2 days at 25 °C	Increased seed germination percentage	Non-stress	Turkey	[84]
11	Carrot leaf extract	Pea	Seeds were primed at 75 mlL^{-1} concentration for 10 hours	Enhanced biochemical and physiological characteristics in drought-stressed plants	Drought stress	Egypt	[85]
12	Chicory, Clerodendron, noni and calotropis leaf extract	Maize	Seeds were soaked in 5%, 10% and 15% chicory extract and 1%, 2% and 3 % of clerodendron, noni and calotropis extractions for 12 hours	Enhanced seedling vigour and yield attributing factors at 12-hour seed priming in 1% leaf extract and foliar nutrition with 2% leaf extract of noni	Non-stress	India	[86]

Plant extracts are commonly prepared as fresh or dry basis [52, 53]. For instance,[53] prepared the plant extract using fresh mature leaves. According to the described method, the extract was extracted from overnight frozen leaves using locally built equipment, and predetermined concentration was prepared by mixing distilled water. [52] described the procedure to prepare the extract by air drying fresh moringa leaves and to store the dried powders at room temperature. The powdered moringa leaves were immersed in distilled water on a weight/volume basis for 24 hours with periodic shaking. The liquid was filtered through four cheesecloth layers and Whatman filter paper to remove fibre debris. Moreover, in some experiments centrifuging process was also carried out as an additional step [57].

4. MECHANISMS OF SEED PRIMING

There are three main phases in the seed priming procedure namely; seed imbibition (phase I), activation phase (phase II) and growth and cell elongation phase (phase III). In phase I, water uptake occurs according to the water potential gradient [11]. In activation phase, most metabolic and repairing actions occur in the cytosol (e.g., protein synthesis, DNA repairing and stimulation of enzymes and antioxidants). During this phase, water imbibition is also continued and numerous cellular activities such as production of ATP, essential lipids and antioxidants take place [87]. Among these activities, DNA repairing is an essential process which protect the cell from oxidative injuries during seed germination [88]. According to latest literature, germination-related enzymes are activated at a higher rate in this phase. For instance, α-amylase activity amplified in wheat seeds after the seed was primed with sorghum water extract [88]. Moreover, seed priming boosted protein synthesis by improving rRNA synthesis and ribosome integrity [11]. Simultaneously, antioxidant enzymes such as peroxidase (POD), superoxide dismutase (SOD), ascorbate peroxidase (APX), glutathione reductase (GR) and catalase (CAT) ensure cellular protection from reactive oxygen species (ROS) [8]. Stage III consists of rapid water uptake, and the radicle's protrusion indicates that the germination process has advanced to the development and cell elongation phases [87].

5. SEED PRIMING THROUGH BOTANICAL EXTRACTS UNDER NON-STRESS CONDITION

Seed germination is the most crucial step in crop cultivation which is considered as an internal process aided by a series of enzymatic reactions, mainly governed by α-amylase [28]. Furthermore, α-amylase gelatinizes the starch in the endosperm, thus supplying ATP energy for the growing embryo [88]. However, presently, commercial crop growers might face numerous consequences related to poor performances in the seed germination process due to non-synchronized germination, an uneven growth pattern, and insufficient seedling emergence [28]. Therefore, to mitigate these constraints, seed priming with numerous composites has been introduced as a viable approach [88].

As a biostimulant, seaweed extracts can be incorporated into the seed coat through priming, stimulating the seed germination rate and initial growth [28]. Seaweed extracts promote seed germination mainly due to the presence of various compounds in the solution. For instance, at different concentrations, seaweed extracts containing various phytohormones would result the germination and initial seedling development process [16]. However, Nonogaki et al. [89] further reported that auxins had not affected seed germination directly, even though they enabled gibberellic acid biosynthesis. Thus, they promoted seed sprouting through activating of α-amylase [89]. Concurrently, primed seed germination enhancement might be impacted by solution-retention effects in the pre-germination phase [20]. Furthermore, some mineral nutrients in the seaweed extract might positively affect the seed germination rate and vigor index [33]. Seed priming through seaweed extraction directly impacts the alternation of seed biochemical properties which accelerates seed germination [33]. According to recent findings, the cell membrane permeability has been reduced in seaweed extract primed chilli seeds. In contrast, electric conductivity is also reduced in the cytosol, resulting from optimum cell functions avoiding damage or solute leakage from membranes [33]. Furthermore, numerous macro and microelements in the seaweed extracts, such as N, P, K, Ca, Mg and Zn, promote initial plant growth and development [25]. These elements act as building blocks of proteins and

other essential substances in the cytoplasm, which play a critical role in osmotic adjustment [25]. Similarly, Ca^{2+} and K^{+} ions included in seaweed extracts catalyze some enzymatic reactions related to seed germination and growth, thus, ultimately enhancing the final yield [36]. The impacts of seaweed extracts on seed priming have been investigated through several experiments. In addition, seaweed extract-primed seeds contained a higher concentration of antioxidants; thus, enhancing the metabolic activities and mitigating ROS production would affect seed growth and development [33].

Similar like to seaweed extracts, plant extracts also contain numerous bioactive compounds. [52, 56]. However, the plant type and area where these plants are being grown altered the bioactive compounds' concentration and composition [53]. Seed priming through leaf extractions enhanced plant growth under normal and stress conditions [53]. For example, moringa leaf extraction consisted of a mixture of mineral nutrients including K, Ca, Mg, vitamin C, and plant growth regulators (e.g., cytokinin), which expedited the cell division, delayed leaf senescence, expanded the leaf area and increased chlorophyll pigments [56]. Furthermore, plants' biochemical attributes would increase after seed priming through moringa leaf extract due to various allelochemicals, including secondary composites such as phenolic and ascorbic acid [53]. Simultaneously, with the enhancement of chlorophyll content, it has been observed that mineral nutrients in moringa leaf extract accumulate in the seed embryo during the seed priming process and facilitate the growth and development of plants [28, 53].

6. SEED PRIMING WITH BIOEXTRACTS UNDER STRESS CONDITIONS

As a result of extreme environmental factors such as drought, salinity, temperature and trace metal (loid) s physiochemical reactions in the plant cells are highly impacted [90]. For instance, Siddiqui al. [90] reported that salinity stress enhanced leaf chlorosis by accelerating chlorophyllase activity which depreciates pigment proteins or enhances the enzymatic chlorophyll degradation process. When plants are exposed to stress conditions, they would stimulate to react to the stress by producing reactive oxygen species (ROS) such as singlet oxygen molecules, hydrogen peroxide (H_2O_2), hydroxyl radicals (OH^{-}), superoxide anion (O_2^{-}); [33,42].

These ROS are involved in the degradation of the thylakoid membrane and hinder the chlorophyll synthesis process [90]. Moreover, [91] observed poor expression of several Mg-chelatase subunit-encoding genes, resulting in low chlorophyll synthesis. In addition, under the salinity stress, water absorption, stomatal conductance nutrient translocation and assimilation [56] were hindered, and this leads to the malfunctioning of cellular activities. In addition, higher salinity level has altered the plant's morphological characteristics by reducing leaf size, developing thicker leaves, and dwarf plants [56]. ROS substances down-regulated gibberellin genes, thus, resulting from low gibberellic acid production and reduction of α-amylase activity [91]. Overall, seed germination and initial plant growth would retard drastically. Apart from ROS, Malondialdehyde (MDA) synthesis is also induced due to lipid peroxidation, and higher accumulation of MDA in plant cells eventually leads to malfunctioning cell functions [92].

However, to combat with ROS compounds plants produce other osmo-regulatory molecules such as proline and glycine betaine [42]. Since proline is an essential amino acid, it makes a defense against oxidative damage that occurs from ROS [93]. Hence, proline accelerates protein hydrolysis and ensures osmatic balance [42]. Further, glycine betaine production in the cytosol also increased and mitigated the most adverse effects of salinity stress [93]. For example, glycine betaine protects cell membranes and proteins, triggers coenzyme activation, and removes excess ROS compounds from the cell [93]. Interestingly, with elevated saline levels, plants would enhance carotenoid production [53] Hence, salinity stress triggers overexpression of genes relevant to carotenoid accumulation under stress conditions, directly involved in reducing free radicles in the cytosol [92].

Seaweed and plant extracts contain unique bioactive compounds (e.g., growth regulators, micronutrients, osmo-protectants, and amino acids) that are essential to accelerate defense mechanisms under abiotic stress environments [56]. The protection mainly occurs due to numerous minerals, amino acids, proline and glutathione induce antioxidant enzyme

production; thus, reducing ROS levels in stressed plants [93]. Moreover, the exogenous application of seaweed extracts and plant extracts further increases the antioxidant concentration in cells, which mitigates ROS production [53]. In this regard, the most common antioxidant enzymes, namely, POD, SOD, APX, GR and CAT concentration, have increased after the priming, which protects the plants from oxidative stress by scavenging ROS [8]. In addition, previous research details provide evidence that even under abiotic stress circumstances, seed priming with seaweed extracts would mitigate the harmful effects of those adverse conditions [29]. For instance, seed priming with moringa leaf extract boosted the initial maize growth due to the presence of phenols and ascorbates [69]. [94] further noticed that MDA production had been reduced after the seed priming.

Abiotic stress conditions widely affect the protein synthesis process in plants. For example, salinity stress induced *Vigna mungo* varieties showed different protein profiles, known as "new stress-proteins" which are highly important to manipulate osmatic potential [93]. The elevated ROS production in cell resulted DNA alternations and produced DNA fragments, resulting in genome instability [95]. The presence of bioactive substances in seaweed extracts would upregulate the polypeptide synthesis by activating specific enzymes [42]. In addition, salinity stress might involve in occurring of mutations, chromosomal rearrangements, and alternations in DNA base arrangement that leads to genotoxic impairment and structural modifications [95. Hence, seed priming through seaweed extracts ensures DNA, protein, and RNA repair and synthesis throughout germination phase II [42].

7. CONCLUSION AND FUTURE PERSPECTIVES

Climate change and other numerous challenging factors negatively influence on the agricultural production. The sustainability of crop production in a changing environment depends on improved seed quality through using environmentally friendly method like seed priming with botanical extracts. Hence, without endangering the environment or human health, it may be possible to promote crop growth and development, boosting of yield and protecting against numerous abiotic stressors. In addition, crop cultivation under stress and non-stressed conditions, seed priming would become more effective tool.

Although seed priming with bio-extracts would have given positive results, further researches are needed to understand the physiological and biochemical impact of bioextracts at seed germination and seedling growth stages. In this regard, future experiments should target on molecular mechanisms engage in seed priming process. Furthermore, studies on undiscovered mechanisms of bioextracts on growth promoting processes would be essential to increase usage of these extracts in crop cultivation. Future researches on direct role of botanical extracts in mobilizing seed reserves and the partitioning of biomass in seedlings is also required. Moreover, seaweed extracts differ from one another even processing the same raw material using different extraction methods. Hence, further crop-specific experiments are necessary to maximize the application of botanical extracts to achieve optimum results. The intensity of this impact varies depending on the species and crop/plant treated. However, the bioextract source varies according to the several factors such as maturity, leaves or shoots contained, location etc. Thus, these factors should be more considered in future experiments. Comprehensive studies should be needed to investigate the biological actions of botanical extracts during seed germination, including the control of ROS, their scavenging by antioxidant enzymes. Hence, more studies are required in future to assess the effectiveness of botanical extracts in minimizing the adverse effects of soil salinization on plants, as well as the ideal dose of application.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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