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Seed Priming with Phytohormones

Musa Saheed Ibrahim, Nathan Moses and Beckley Ikhajiagbe

Abstract

Improving growth and yield properties of plants has been the major aim of most researchers in plant science field. Several strategies have been suggested in order to sustainably improve crop yield. Among these strategies is biopriming, has gained the highest attention being the most effective strategy. Biopriming is a technique involving pre-soaking of plant seed into a solution in order for the metabolic processes to be enhanced before to germination, thereby improving the percentage and rate of germination and increase seedling growth and crop yield under normal and different environmental stresses. The most important aspects of phytohormones is that they are very essential in the regulation of plant development and growth and also functions as an essential chemical messengers, allowing plants to thrive even during exposure to various stresses. Priming plant seeds with phytohormones has led to improved growth and yield of plants in developing countries. Furthermore, it has emerged as an important tool for mitigating the effects of environmental stress. However, this innovation has received less attention from local farmers and merger work has been reported. Therefore, this review discusses the mechanism and potential role of priming with phytohormones to enhance crop productivity and improve plant tolerance to biotic and abiotic stressors.

Keywords: biopriming, phytohormones, plant growth regulators, biotic stress, abiotic stress

1. Introduction

Plant hormones since their discovery in seventeenth century have been used extensively in crop production. Advent of technology allowed the researchers to study more about different plant hormones and their endogenous and exogenous uses [1]. Plant hormones are a group of naturally occurring organic substances that are produced by plants and has effects on plant physiological processes when released at low concentrations. Plant hormones also referred to as phytohormones have the ability to influence growth, differentiation, development, and stomatal movement [2]. These hormones are well known for their important roles in plant physiology such as regulation of plant growth and development and important chemical messenger [3]. The first plant hormone that was identified was auxin. This plant hormone has a wide range effect on plant growth and development. Recently, it has been clearly shown that plant hormones are not exactly like the mammalian hormones. Even though the synthesis of plant hormone may be localized as in the case of animal hormones, but plant hormones may be transported to a long distance where it is needed most [4]. Auxins (IAAs), cytokinins (CKs), gibberellins (GAs),

abscisic acid (ABA), salicylic acid (SA), and ethylene (ET) are of the most essential phytohormones that are important for plant growth and development [5, 6]. These plant hormones have series of ways by which they improve growth and development of plants.

Strategies and mechanisms of growth promotion by phytohormones have been assessed, and several hormones have been categorized in different classes [7]. Major functions of these phytohormones are cell enlargement such as in auxin [6]. Cell division such as auxin, which stimulates the division of cells in the cambium and sometimes together with cytokinin in tissue culture media [3]. Vascular tissue differentiation such as in indole acetic acid which stimulates fast differentiation of phloem and xylem, initiation of plant root, and also the development of secondary roots under normal growth media and tissue culture media [6]. In most cases for plants, synthesis of hormones and plant response determines plant health and may in turn improve soil fertility [8]. Plant hormones have been very helpful in sustainable agriculture by stimulate fast growth and development in plants, which can be achieved through processes such as by spraying on the leaf and other plant tissues [7]. It is now important to consider introducing the endogenous and exogenous plant hormones into the growing seeds to improve stimulating rates. This process is called seed bioprimering.

Seed bioprimering is a unique innovation where seeds are treated with biological substances (such as bacteria, fungi, and hormones) that assimilates plant morphology and physiological facets [9]. This process has also been used to fortify plant against diseases [10]. Hormonal primering is a situation where plant seed are prime with phytohormones. This process has been documented to influence seed metabolism and germination rate. This technique has now been adopted in developing countries to enhance seed germination, growth of seedlings, and crop yield in environmentally disturbed arid lands [11, 12]. Ensuring better germination, improved plant growth and seedling vigor through seed bioprimering would result in healthy and productive plants. There are several approaches to seed primering, however, all followed similar mechanisms and are used in improving plant growth properties [8]. Therefore, the purpose of this review is to summarize the effectiveness of seed primering using phytohormones in enhancing crop productivity along with future prospects of this innovative technology. In order to achieve this, this review discusses mechanisms involved in hormonal seed primering, hormone specific in seed primering, bioprimering and crop productivity, role of hormonal primering in plant stress mitigation, economics of hormonal primering and future prospects of hormonal primering.

2. Mechanisms involved in seed bioprimering

There are several approaches used in bioprimering such as hydro primering which involve soaking seeds in distilled water and oven drying at low temperature before sowing. This process does not involve the use synthetic chemicals which makes it faster, cheaper, and eco-friendlier [13]. Osmo-primering has also been considered by local farmers in Brazil where seeds are soaked in salt-containing solution. This process allows slow imbibition of water into the seed and that initiate energy activation [14]. Hormoprimering which involves the soaking of seeds in naturally occurring plant growth regulators. This process has direct effect on processes of seed metabolism. Usually, scientist considered abscisic acid, auxins, gibberellins, kinetin, ethylene, polyamines, and salicylic acid as the hormones widely used in primering [15]. For example, Galhaut et al. [16] confirmed the effectiveness of gibberellic acid in improving photosynthetic properties, antioxidant system, seedling

Figure 1.
 Schematic model indicating the strategy of seed priming and the possible results.

emergence, and growth in white clover plant grown on heavy metal polluted soil. Other strategies such as chemo-priming [17], nutri-priming [18], and plant growth promoting bacteria rhizobacteria (PGPRB) priming [19, 20] have proved effective in promoting growth properties of plants.

Generally, mechanism involve in seed biopriming include pre-soaking of seeds with a particular concentration of priming agent such as water, PGPRB, or phyto-hormone (**Figure 1**). This process improves germination parameters, seedling yield and growth, by either increasing nutrient utilization with the help of an improved physiological activities and root cell differentiation and division [21, 22], or by stimulating the activation of important metabolites such as amylase which initiate energy supply and improve germination properties [17]. Previous researches have documented evidence on seed priming with phytohormones in varieties of plant species and how important physiological processes such as growth and develop-ment, respiration, and transpiration are improved [23, 24]. The results of these researches have shown the significant roles of phytohormones in the biochemical, defense, and signaling pathways of plants [6]. Many researchers are now working to develop effective approaches to alleviate biotic and abiotic stresses and enhance crop production, especially as the world is constantly facing global warming. Seed priming with phytohormones can modulate the physiological and genetic mecha-nisms, making plants capable of tolerating these environmental stresses or making plants resistance to the stressors. These mechanisms if well adopted would be promising.

3. Hormone specific in seed biopriming

There are various plant hormones produced by plants which have various functions. However, auxins, cytokinins, gibberellins, abscisic acid, salicylic acid, and ethylene are the most frequently used in seed priming. In addition, methyl jasmonate have also been used by previous literature in seed priming. According to

S/N	Plant	Abiotic stressor	Phytohormone	Response	Reference
1.	Rice (<i>Oryza sativa</i>)	Salt	Auxin	Modulate ion homeostasis in rice plant	Iqbal and Ashraf [25]
2.	Soybean (<i>Glycine max</i>)	Drought	Cytokinin	Enhanced drought tolerance in soybean plants	Mangena [26]
3.	Wheat (<i>Triticum aestivum</i>)	Salt	Cytokinin	Decreased electrolyte leakage and improved salt tolerance	Angrish et al. [27]
4.	Pot marigold and sweet fennel	Salt	Gibberellin	Improved dry matter and increased tolerance to salinity by enhancing antioxidant enzyme activities	Sedghi et al. [28]
5.	Sorghum (<i>Sorghum bicolor</i>)	Drought	Gibberellin	Increased CAT and APX activities	Sheykhabglou et al. [29]
6.	Rice (<i>O. sativa</i>)	Flood	Gibberellin	Increased α -amylase activity, sucrose, glucose, and fructose content in seeds.	Watanabe et al. [30]
7.	Maize (<i>Zea mays</i>)	Salt	Gibberellin	Reduced negative effect of salt stress	Hamza and Ali [31]
8.	Wheat (<i>T. aestivum</i>)	Salt	Absciscic acid	Increased α -amylase activity, sucrose, glucose, and fructose content in seeds.	Zongshuai et al. [32]
9.	<i>Agropyron elongatum</i>	Temperature	Absciscic acid	Enhanced anti-oxidant enzyme activities	Gurmani et al. [33]
10.	Rice (<i>O. sativa</i>)	Chromium	Salicylic acid	Enhanced antioxidant enzyme activities, detoxified ROS	Pouramir-Dashtmian et al. [34]
11.	Maize (<i>Z. mays</i>)	Chilling	Salicylic acid	Enhanced enzymatic antioxidant activities, high tissue water content	Farooq et al. [35]
12.	Lucerne (<i>Medicago sativa</i> L.)	Cadmium	Jasmonic acid	Increased α -amylase activity and sugar content	Watanabe et al. [30]

S/N	Plant	Abiotic stressor	Phytohormone	Response	Reference
13.	Rice (<i>O. sativa</i>)	Salt	Ethylene	Increased α -amylase activity and sugar content	Dai et al. [36]
14.	Sorghum (<i>S. bicolor</i> L.)	Iron toxic soil with high pH	Indole acetic acid, gibberellin, and ascorbic acid	Improve seed germination even under elevated pH levels	Onoabhagbe et al. [37]
15.	Sorghum (<i>S. bicolor</i> L.)	Iron toxic soil	Indole acetic acid, gibberellin, and ascorbic acid	Improved germinability and germination properties	Beckley et al. [38]

Table 1.
Seed priming with phytohormones for developing abiotic stress tolerance in plants.

several plant hormones function in seed germination and energy production for the developing embryo.

3.1 Gibberellin

Gibberellins (GAs) are plant hormones that have shown the capacity to regulate different developmental processes, such as stem elongation, germination, dormancy, flowering initiation, flower development, fruit development, and leaf and fruit senescence [3]. Gibberellin brings results that are somewhat similar to the ones by auxin, even though their mode of action differs [21].

Furthermore, gibberellin plays an essential function various physiological and developmental stages in plants (**Table 1**), but they are more effective in making stems increasing stem elongation through rapid cell differentiation and cell circle [3], Thereby leading to internode elongation. Dwarf and rosette plants (plants with little space between nodes on a stem or plants with clustered base) have been investigated to have low or no concentration of gibberellin. Also, Onoabhagbe et al. [37] used gibberellin and other plant hormones to improve germination properties and growth of *Sorghum bicolor* under elevated pH regime using chemoprming system.

3.2 Auxin

Auxin (IAAs) were also one of the most essential and the first identified phytohormone. IAA phytohormone is known to show an essential role in modulating plant growth and developmental processes, especially the root growth, cell elongation, vascular differentiation, and apical dominance [3]. IAAs also play an important function in cell division and differentiation, in fruit developmental stages, in the root formation from cuttings, in the lateral branching (apical dominance) inhibition, and in the leaf fall (abscission) frequencies. IAA conjugates is usually the form assumed by IAA in higher plants, IAAs conjugates functions as the primary free endogenous auxin that brings about plant developmental processes. The exogenous priming of seeds with IAAs induces the fast and improved formation of adventitious roots and lateral roots [39].

One of the most important naturally existing auxin is β -indolylacetic acid (IAA), which is obtained either from the amino acid tryptophan or from the breakdown of carbohydrates known as glycosides. This chemical influence plants by its activity

on the chemical bonds linking carbohydrates present in plant cell walls. The cycle allows the cells to be irreversibly adjusted and is joined by the passage of water and the synthesis of new cell wall material.

Auxin is engaged with cell development and cell extension of certain parts of a developing plant such as the stem which produced basically in pieces of the plant that are effectively developing like the stem (specifically, the stem tip). The phototropic reaction happens on the grounds that more amounts of auxin are disseminated to the side away from the light than to the side toward it, making the concealed side stretch all the more firmly and accordingly bend the stem toward the light. Additionally, the geotropic reaction happens in light of the fact that more auxin gathers along the lower side of the developing stem than along the upper side, creating a vertical arch.

3.3 Cytokinins

Cytokinins (CKs) are one of the plant hormones that are known to regulate various sections of plant growth and development, such as cell division, apical development, root elongation, stomatal behavior, and chloroplast synthesis [26]. It has been widely documented that application of CKs can promote crop development and yield. For example, Fricke et al. [40] demonstrated the use of CKs to improve cotton seedlings development. The result showed an increase in cotton yield of 10%. Another important aspect of CKs is its ability to improve pathogenesis in plant. Furthermore, CKs application has showed resistance against *Pseudomonas syringae* in *Arabidopsis thaliana* [28] and *Nicotiana tabacum* [31]. CKs are majorly produced in the root regions from a compound known as adenine. They are found moving upward within xylem (woody tissue) and then pass it to the leaves and fruits, where they are needed for growth and cell differentiation in plants.

CKs also functions together with auxin to reverse senescence in plants through stabilizing protein levels and synthesis of chlorophyll in the leaf. Senescence is a developmental stage in plant when the yellowing of leaves is visible as a result of protein breakdown and chlorophyll is decomposition. CKs also can also be used in the storage of green vegetables to reduce yellowing [7]. In horticultural tissue culture, according to Addicott [41], increased auxin and reduced cytokinin conditions can lead to improved root development, while reduced auxin and increased cytokinin conditions can lead to improved shoot development.

3.4 Ethylene

Ethylene (ET) is another essential plant hormone that influence ripening and rotting of fruit in plants [42]. ET is a very important plant hormone because it is the only plant hormone occurring as a gas. Furthermore, ET can be synthesized in almost every part of a plant, and can diffuse as a gas through the plant's tissue, outside the plant, and travel through the air to affect other plants within the vicinity. For example, Montalvo et al. [43] reported accelerated mango ripening as a result of application of ET for 12 hours. This process stimulating process was achieved through the production of 1-amino cyclopropane-1-carboxylic acid (ACC: an ethylene precursor) and improved ACC oxidase activity.

3.5 Absciscic acid

Absciscic acid (ABA) is another essential plant hormone that is known to stimulate developmental processes in plants, such as bud elongation, dormancy, control of organ size, and stomatal closure. It is also known as stress hormone because it

plays essential function in regulating plant responses to various biotic and abiotic environmental stressors such as drought, salinity, cold, heavy metals stress, and heat stress. ABA is a stress-triggered hormone, such that the highest concentration of ABA is synthesized in the root region of plant in response to decreased soil water potential (which is associated with dry soil) and other stress induced conditions. After the synthesis, ABA is then translocated to the leaves regions, where it gradually affect the osmotic potential of stomatal guard cells, causing them to shrink, leading to the closure of stomata. The ABA-induced stomatal closure brings about reduced transpiration (evaporation of water out of the stomata), thus preventing further water loss from the leaves in times of low water availability. A close linear correlation was found between the ABA content of the leaves and their conductance (stomatal resistance) on a leaf area basis.

3.6 Salicylic acid

Salicylic acid (SA) is also an essential plant hormone, belonging to the phenolic group. It has various physiological benefits in plants because of its ability to regulate the processes of growth and development in plants such as photosynthesis, respiration, transpiration, and the transportation of ions in plants. According to Devinar et al. [44], Khan et al. [45], Senaratna et al. [46], and Bastam et al. [47], SA exhibits an essential role in the activation, modulation, and regulation of numerous responses during plant exposure to abiotic and biotic environmental stresses. Fahad and Bano [39] reported that SA has the capabilities to initiate and generate a cascade of several signaling pathways by interacting with other plant hormones such as ABA and ET and plays an important role in mitigating plant stresses. Ikhajiagbe and Musa [15] investigated the effect of SA on germination and early seedling growth of pigeon pea (*Cajanus cajan*). The research showed that increased levels of SA at 20 mg/L is very essential for maximum seed germination and early seedling growth of *C. cajan*. Furthermore, Jadhav and Bhamburdekar [48] observed the positive influence of SA on the root and shoot growth of groundnut. Anaya et al. [49] indicated the significant contribution of SA in alleviating saline stress in *Vicia faba* under salt stress condition.

4. Bio-priming with phytohormones and crop productivity

According to Khan [50], seed priming involves various physiological treatments that can improve seed germination and seedling vigor through the addition of effective plant hormones. Ikhajiagbe and Musa [15] reported that pigeon pea (*C. cajan*) seeds bioprimered with salicylic acid for 20 hours results in improved germination properties. Malathi and Doraisamy [51] observed that seed priming with gibberellins protected seeds of groundnut from the infection of *Macrophomina phaseolina* and also bring about improved seedling vigor, plant dry matter, and prevented loss of oil content for up to 6 months of storage. Mohamedy et al. [52] discovered that bioprimering of pea seeds with ethylene showed significant decrease in pre-emergence damping off, that is occasioned as a result of infestation by *Fusarium solani* in abandoned soils. Sarkar and Bhattacharyya [53] observed that the mung bean seeds when soaked in suspension of a particular hormones such as cytokinins and auxin brought about reduced root rot incidence in pot experimental set up and also resulted in increased root length, shoot length, dry weight of seedling, and yield as against the control setup. Furthermore, Mohamedy and Baky [54] discovered that bioprimering of pea seeds with abscisic acid indicated the highest survival and lowest root rot disease incidence. In addition, highest plant height, enhanced leaves and

branches numbers per plant, dry weight of shoots per plant, pod length and diameter, numbers of seed per pod, and lowest chlorosis percentage were observed.

5. Role of hormonal priming in resistance against abiotic stress

Different phytohormones have shown effects in improving germination properties and plant growth under abiotic stress (**Table 1**). Abiotic stress is the negative impact of all non-living factors on living organisms in a specific environment [55]. For example, auxin is very important in plant developmental processes such as translocation of carbohydrates as it improves lateral root formation, photosynthetic activities, flowering, and adventitious root development, by so doing, the plant extend its root deep down the soil to obtain water needed for its developmental stages in case of drought stressor [56]. Similarly in case of insufficient nutrient, the adventitious roots can conduct needed nutrients for plant developmental use [57]. According to Roohi and Jameson [58], seed priming with auxin improved the seedling establishment, improved tolerance to drought stress of *Bouteloua gracilis*. This improvement was achieved by enhancing catalase (CAT), superoxide dismutase (SOD), and peroxidase (POD). Fahad et al. [59] observed priming seeds with auxin had improved germination and growth of rice (*Oryza sativa*) and pigeon pea (*C. cajan*), under model of arsenic and cadmium stress.

Seed priming with cytokinin has resulted in the alleviation of abiotic stresses in various plant species such as wheat and soybean by enhancing chlorophyll (Chl) formation thereby improving photosynthetic rate, enhancing membrane stability, and regulate ionic levels under drought stress [26, 60]. However, the further explanation on the mechanisms of how priming with cytokinin mitigate abiotic stress have not been fully understood. However, it may be as a result of its enhancement of chlorophyll formation and enhances stomatal movement thereby improving energy efficiency through photosynthesis [61].

Seed priming with gibberellin in addition with poultry manure has enhanced the growth of pepper (*Capsicum annuum*) plants and improved their salinity tolerance [62]. According to the use of gibberellin to tomato seed (*Solanum lycopersicum*) improved relative leaf water content, stomatal density, and Chl content by mitigating salinity stress.

Wei et al. [63] observed that priming of rice seed with abscisic acid has enhanced the growth rate, survival rate, biomass accumulation, and root formation under of rice under alkaline stress. Similarly, seed priming with abscisic acid improved salinity tolerance thereby leading to enhanced growth properties of rice, wheat, and sorghum [33, 64]. A similar result was reported by Fricke et al. [40] on barley leaves growth through the down regulation of the water loss during transpiration under saline conditions.

Seed priming with salicylic acid have also showed improved growth properties in heavy metals stressed environment Fahad and Bano [39] and Ikhajiagbe and Musa [15]. The application of different levels of salicylic acid was observed to enhance maize (*Zea mays*) yield even under low temperature. Furthermore, garden cress (*Lepidium sativum*) germination and developmental properties as well as seedlings height under salinity stress were enhanced with the application of salicylic acid. Drought stress was also mitigated, while vegetative growth was improved in safflower (*Carthamus tinctorius*) after the application of salicylic acid [65]. Priming of soybean (*Glycine max*) with a combination of ethylene and jasmonic acid had mitigated waterlogging stress by expression of glutathione transferases which led to the promotion of the adventitious root initiation and increasing root surface area [42].

6. Role of hormonal priming in resistance against biotic stress

Plants are sessile organisms and therefore cannot move away from its locations in case of environmental stress. For this purpose, plants through evolution have developed series of defense mechanisms. These defense mechanisms can be stimulated either where toxic secondary metabolites are stored; or can be inducible, where defense is activated upon detection of an attack. Plants have the ability to easily detect environmental stress conditions, therefore upon sensing it, they rapidly activate their regulatory or transcriptional machinery, and eventually generate an appropriate response (defense mechanism). Over the years, scientist have gone deep into the research on how plant active their mechanisms against pathogen attack, however, the interplay and impact of different signals to generate defense responses against biotic stress still remain elusive. Seed biopriming with phytohormones has been used in various plant species for the biocontrol of various pathogenic attacks. Abuamsha et al. [66] and Dey et al. [67] applied abscisic acid to the different oil seed rape cultivars which helps in the control of a pathogen causing blackleg disease. The pathogen was observed to be reduced to about 71% after phytohormone application. Muller and Berg [68] reported the role of gibberellin in controlling the damping-off disease in varieties of plant species, especially in cucumber [3].

7. Economics of biopriming

Previous researches have shown biopriming with phytohormones to be easier, fast, cheaper, and more environmentally friendly as against the chemical processes. With the enhancement in crop productivity witnessed in biopriming, it have been accepted the potential technique for biocontrol of several plant pathogens. Before now, farmers can only control insect infestation and pathogens attacks through the application of costly and non-ecofriendly pesticides. But with the introduction of hormone priming techniques, plant productivity and pathogens attack can be alleviated through hormone priming. Bio-priming is directly involved in the enrichment of plant development and which improves germination rate, uniformity in plant population, increases water and nutrient use efficiency, eliminates seed borne pathogens, controls pests and diseases. Besides these advantages, bio-priming reduces the hazardous effects on humans caused by the use of fungicides, bactericides, and pesticides by supplementing the chemicals with a sustainable strategy.

8. Conclusion and future prospects

Seed priming using plant hormones has shown to be a promising and innovative technique in improving germination parameters as well as growth and yield of varieties of plant species. It has as well showed signs of effectiveness in plant abiotic and biotic stress management. Seed priming with phytohormones result in increased antioxidant secretion and activities, thereby reducing oxidative stress, leading to plant growth and yield enhancement. Therefore, seed hormoprimering have the capacity to be utilized for sustainable crop production even under environmental stress. Seed bioprimering have also proven to improve seedling health and also improves imbibition rate by breaking dormancy and improving viability. This review shed more light on the successes recorded as a result of using phytohormones in fortifying seeds prior to sowing as it serves as early treatment to plants thereby stimulating all important enzymes at early stage. The information in this

review can be used for developing future research on plant growth improvements and would inform modern farmers on the need to consider this important strategy. This emerging strategy has proven to be an effective seed treating technique for many crops. However, phytohormones concentration and priming duration may differ from crop to crop. For example, excessing seed priming and for longer period may lead to desiccation and decomposition of seed or bacteria infestation which makes seeds unviable. Future research at OMICs levels may be required to further explain the mechanisms employed by these phytohormones in seed priming, especially on how it reduces biotic stress in plant. Researches at molecular level is also required to further clarify on pathways involve and influence of priming duration and concentration of the phytohormones.

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Conflict of interest

The authors declare no conflicts of interests.

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