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Editorial

Seed Priming Technology: Current Perspectives

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Seeds are vital components in the life cycle of plants, as they are responsible for the propagation of new plant generations. Seed germination and early seedling development are delicate stages in the plant growth cycle, especially when faced with challenging environmental conditions. Additionally, certain plant species require a period of dormancy before restarting growth. Seed dormancy is a state where a seed is unable to germinate, even when provided with optimal conditions for growth [1]. Various techniques have been employed to enhance seed germination and seedling growth under optimal and stress conditions in both orthodox and dormant seeds. Seed priming facilitates germination by controlled hydration and dehydration of seeds prior to sowing, and it has been extensively utilized to boost germination rates and seedling development under various stressors [2–5]. This practice is highly effective in ensuring uniform germination, making it a valuable tool for nurseries. Similarly, different compounds applied during imbibition have proven effective for research purposes and to enhance seed germination and seedling vigor [6].

In that regard, this Special Issue welcomes reviews and experimental research that explore physiological, biochemical, and molecular aspects related to the effect of seed priming on germination and seedling establishment and regarding their interaction with environmental stresses. Seed priming has been proven to improve seed germination in a wide range of plant species and is currently used by seed companies to improve seed germination and plant performance. In an excellent review published in this Special Issue, Corbineau et al. [7] presented extensive information on hydropriming and osmopriming techniques to improve germination, making it faster and more uniform, even in aged seeds, and correlating this with a decline in lipid peroxidation and the increase in reactive oxygen species (ROS)-scavenging enzymes [7]. Hydropriming can be defined as the immersion of seeds in water for a specific time period, whereas osmopriming can be defined as the immersion of seeds in aerated solutions of low water potential (-1.0 to -2.0 MPa), such as polyethylene-glycol, sugars, alcohol, or different salts, including nitrates, phosphates, and chlorides, among others [7]. Currently, omics technologies enable us to gain a deeper insight into the seed priming process as a whole, including the identification of translation initiation factors and genes involved in DNA methylation or acetylation. A better knowledge of the biochemical and molecular mechanisms involved in the effects of priming on seed germination could allow the discovery of molecular and biochemical markers for different priming treatments [7].

Some of the works included in the Special Issue have evaluated the use of potassium nitrate (KNO_3) treatments on germination and early seed growth in the presence or absence of NaCl. The germination of the halophyte *Lobularia maritima* decreased in the presence of 100 and 200 mM NaCl and was even inhibited by 300 mM NaCl. However, the germination rate was improved by the seed priming treatment with 10 mM KNO_3 or 50 mM thiourea, both in the presence and absence of saline treatment. Other seed priming treatments, such as 10 µM salicilyc acid or 1 mM proline, even produced negative effects in the presence of 50 mM NaCl [8]. The positive effect of KNO_3 in seed germination could be dependent on the plant species. In this case, Adhikari et al. [9] described that in the presence of 100 mM

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NaCl, both 50 mM KNO_3 and 3 mM gibberellic acid (GA_3) treatments had no positive effects on the germination of *Lactuca sativa* L. seeds, in terms of germination parameters, morphological traits, or biomass accumulation [9]. However, the hydro-priming of *Lactuca sativa* L. seeds (distilled water soaking for 2 h 30 min) reached a better synchronized germination under NaCl stress but also a higher biomass accumulation, which correlated with the lowest electrolyte leakage (EL) values in relation to the other priming treatments and the non-primed seeds. EL is considered as an oxidative stress parameter that indicates membrane damage [10]. Thus, these results suggest that hydro-primed seeds showed the lowest membrane damage, under salt stress than the other treated seeds.

The effect of KNO_3 in seed germination can also depend on the concentration used for the priming treatment. Hernandez et al. [11] described a positive effect of low KNO_3 levels (0.25 mM) on early pea seedling growth that correlated with a higher water uptake rate during the germination process. However, higher KNO_3 levels (40 mM) reduced the seedling growth. This latter response correlated with a decrease in the activity of H_2O_2-scavenging enzymes, ascorbate peroxidase (APX) and peroxidase (POX), and with the lowest reduced ascorbate contents, accumulating the oxidized form of ascorbate [11]. The effectiveness of KNO_3 in breaking seed dormancy, stimulating seed germination, and ensuring uniform growth in different plant species has also been reported. Nevertheless, the specific mechanism by which KNO_3 enhances seed germination and seedling establishment remains unknown [12]. Studies suggest that plant hormones are essential for the germination process, and it has been shown that KNO_3 can modify the levels of GA and abscisic acid (ABA) during germination [13]. In their study, Hernandez et al. [11] reported that seed priming treatment with low KNO_3 levels (0.25 mM) strongly increased the GA_1 concentration in pea seedlings and reduced the level of ABA in both pea seedlings and cotyledons, leading to a significant decline in the ABA/GAs ratio.

It is well known that salinity impairs seed germination in all plant species, and in addition, soil salinization is an increasing challenge. Other works in this Special Issue have also addressed the use of seed priming treatments to improve seed germination under saline conditions. In this regard, Kataria et al. [14] studied the role of Ca^{2+} and cyclic GMP to mitigate the negative effects of salinity on germination through the magnetopriming of soybean seeds. The authors found that salinity (50 mM NaCl) declined different parameters related to seed germination (early seedling growth, vigor index, total amylase, protease, and nitrate reductase). However, magnetopriming and Ca^{2+} treatment enhanced all of these measured parameters along with a remarkable increase in ROS and nitric oxide (NO) content. The authors concluded that exposure to a magnetic field can activate calcium receptors and target proteins, leading to enhanced calcium and cGMP signaling. This signaling pathway may trigger ROS and NO production, which in turn may activate total amylase, protease, and nitrate reductase activities, accelerating seed germination and promoting seedling growth under salt stress [13]. Salicylic acid (SA) and H_2O_2 were tested during kidney bean germination in the presence of 150 mM NaCl [15]. The authors reported that salinity produced a decrease in different parameters related to seed germination, such as percentage of germination, germination index, seed vigor index, shoot length, root length, and plant growth. The results showed that SA and H_2O_2 treatments, as well as hydropriming, stimulated all the mentioned parameters and enhanced the relative water content and photosynthetic pigments in kidney bean seedlings. The authors concluded that exogenous applications of SA and H_2O_2 can improve salt tolerance and enhance germination and seedling features of kidney beans [15].

The effect of H_2O_2 on seed germination and seedling performance in peach was also investigated by Barba-Espín et al. [16]. The authors found that H_2O_2 imbibition of peach seeds without endocarp after 8 weeks of stratification increased germination rate and resulted in seedlings displaying good vegetative growth. The H_2O_2 imbibition also affected the levels of ascorbate (AsA) and glutathione and produced a decrease in abscisic acid and an increase in jasmonic acid in peach seedlings. Thus, H_2O_2 priming reduced the stratification period needed to germinate peach seeds, which can bring practical application to peach breeding programs and nurseries, as well as to other *Prunus* species [16].

In recent years, seed priming with AsA has been successfully used as a strategy to improve germination and plant productivity, given its crucial role during seed germination. In an excellent review, Terzaghi and De Tullio [17] detailed very interesting aspects of ascorbate metabolism and the dynamic regulation of the AsA system during seed development and seed germination, including the changes detected in the reduced and oxidized forms of ascorbate and the activity of the enzymes APX, monodehydroascorbate reductase (MDHAR), and dehydroascorbate reductase (DHAR). Moreover, changes in the expression of the genes involved in the biosynthesis of AsA, genes encoding for APX, and genes involved in its recycling (different MDHARs and DHARs) were also described [17]. The authors showed evidence that priming seeds with AsA at different concentrations is beneficial to plant growth, development, and productivity, both in the absence or in the presence of some stressors such as NaCl [17].

The role of melatonin as an antioxidant is well known, both in plants and in animals [18]. In that regard, García-Cánovas et al. [19] studied the effects of melatonin on germination and seedling growth under stress conditions, i.e., aging seeds and under polyethylene glycol (PEG)-induced drought stress. Melatonin improved germination in aged seeds at different concentrations, with a maximum effect at 20 µM in rice and 0.05 µM in barley and shorgum. In general, melatonin priming also showed a positive effect on early seedling growth in terms of shoot and root length and biomass accumulation. The PEG-induced drought conditions negatively affected all the germination parameters in sorghum. However, the presence of melatonin reverted and even improved all these germination parameters [19]. The authors concluded that priming seeds with melatonin under low germinability conditions relieves stress and improves both germination and seedling growth, and that this effect could be linked to the antioxidant capacity of this molecule increasing the antioxidant mechanisms, thus controlling the ROS overproduction that takes place under stress conditions. Moreover, the role of melatonin modulating plant hormone contents in tissues should not be ruled out. Consequently, melatonin can act through the modulation of the redox network and plant hormonal responses during the germination process [19].

One of the contributions to this Special Issue involved a transcriptomic analysis using RNAseq technology to explore the molecular mechanisms of osmoprimed *Solanum paniculatum* seeds growing under adverse conditions. The study found that PEG-treated (−1 MPa osmotic potential) seeds had better germination rates under drought stress compared to non-primed seeds, leading to their selection for transcriptomic analysis. Out of 34,640 transcripts, 235 showed differential expression between osmoprimed and water-imbibed seeds, with 232 being upregulated and three being downregulated [20]. The results of differentially expressed transcripts revealed the upregulation of genes encoding proteins related to water, oxidative, saline, and heat stresses as a result of osmopriming, indicating a possible cross-tolerance effect [20].

As a general conclusion, we can state that priming is a commonly employed method to enhance seed quality and facilitate quicker and more uniform seed germination. Currently, priming techniques are widely used at the commercial level. The works published in the Special Issue present information that relates priming techniques with the modulation of antioxidant machinery and the hormone profile (ABA, GAs) in the seeds. In addition, ROS, such as H_2O_2, are able to increase germination in peach through the modulation of AsA, glutathione, and some plant hormones (ABA, JA) levels in peach seedlings. The role of AsA metabolism in seed germination was remarked on in an interesting review as the modulation of ascorbate-related enzymes. The role of antioxidants in seed germination was confirmed by the effect of melatonin on this important process. Furthermore, the Special Issue highlighted that priming can also enhance the germination of low-vigor or old seeds from different species, as well as those subjected to environmental stresses such as salt and drought. Finally, to understand the molecular mechanisms developed by primed seeds to grow under adverse conditions, transcriptomic analysis using RNAseq technology can provide us with very interesting information.

Conflicts of Interest: The authors declare no conflicts of interest.

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