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Environment

Corn seed conditioning with ultraviolet light to mitigate salt stress

Condicionamento de sementes de milho com luz ultravioleta para mitigação do estresse salino

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ABSTRACT

Seed priming with ultraviolet light is considered an effective seed treatment method that can promote synchronized germination and development, contributing to better performance in mitigating the negative effects caused by abiotic stress. The objective of this study was to analyze the effects of conditioning maize seeds with UV-C light under salinity-induced stress. Seeds were exposed to two doses of UV-C and sodium chloride. The seeds were sown on germitest paper, and the rolls were kept in a germination chamber (25 ±2 °C and 12 h photoperiod). Germination and seedling growth parameters were evaluated. The high salt concentration resulted in a lower percentage of germination and initial seedling growth. Pre-exposure of maize seeds to UV-C radiation proved to be effective in mitigating the deleterious effects of excess salt on both seed germination (3.42 kJ m^{-2}) and seedling growth (0.85 and 3.42 kJ m^{-2}). Therefore, it can be concluded that the application of UV-C light to condition maize seeds may be a promising strategy to mitigate the adverse effects of high salt concentrations.

Keywords: Conditioning; Germination; Radiation; Salinity; Ultraviolet; *Zea mays*

RESUMO

O priming de sementes em luz ultravioleta é considerado um método eficaz no tratamento de sementes, podendo promover a germinação e o desenvolvimento sincronizados, contribuindo para um melhor desempenho na mitigação dos efeitos negativos causados por estresses abióticos. Assim, este estudo teve como propósito analisar o impacto do condicionamento de sementes de milho com luz ultravioleta-C sob estresse induzido por sal. As sementes foram expostas a duas doses de UV-C e cloreto de sódio. A semeadura ocorreu em papel germitest e os rolos foram mantidos em câmara de germinação (25 ±2 °C e fotoperíodo de 12 horas). Foram avaliados parâmetros de germinação e crescimento das plântulas. A alta concentração salina resultou em menor percentagem de germinação e crescimento inicial das plântulas. A pré-exposição das sementes de milho à radiação UV-C mostrou-se eficaz na atenuação dos efeitos prejudiciais do excesso de sal, tanto na germinação das sementes (3,42 kJ m^{-2}) quanto no crescimento das plântulas (0,85 e 3,42 kJ m^{-2}). Assim, pode-se concluir que a aplicação de luz UV-C no condicionamento das sementes de milho pode ser uma estratégia promissora para mitigar os efeitos adversos decorrentes de altas concentrações de sal.

Palavras-chave: Condicionamento; Germinação; Radiação; Salinidade; Ultravioleta; *Zea mays*

1 INTRODUCTION

There is a growing interest in studying the effects of ultraviolet (UV) radiation on plants, considering the morphological, physiological, and biochemical effects that can affect their development. Initially, UV radiation was applied to microorganisms because of its germicidal power (Tran et al., 2022). However, recently, a new conditioning technique using C-band ultraviolet radiation (UV-C) on dry seeds has been implemented (Sadeghianfar et al., 2019; Alamer & Attia, 2022).

Due to its energy, UV-C exposure requires treatment times in the order of minutes (Alamer & Attia, 2022). Several studies indicate that UV-C seed priming has been adopted as an alternative to reduce the negative effects of high salt concentrations and increase crop productivity (Ouhibi et al., 2014; Xu et al., 2019; Alamer & Attia, 2022; Hossinifarahi et al., 2022; Atta et al., 2023; Fgaier et al., 2023; Stefanello et al., 2024).

Population growth requires increased cereal consumption and intensification of productivity. Soil degradation because of abiotic pressures such as salinity leads to poor agricultural production, exacerbating the problem (Islam et al., 2022). In addition, the intensification of climate change, inadequate irrigation, heavy metal toxicity, high concentrations of ions (Na^+ and Cl^-), lack of nutrients, and human intervention have become major factors in the degradation of agricultural systems and decline in productivity (Bailey-Serres et al., 2019; Sinha et al., 2021). The undesirable effects of salt stress on plants result in low germination percentage, stunted growth, inhibition of photosynthesis, oxidative stress, loss of electrolytes, and disorganization of cell membranes (Ji et al., 2022; Hannachi et al., 2022).

Maize plants undergo various physiological changes due to osmotic stress, toxicity of certain ions, and nutrient imbalance caused by excess salt (Islam et al., 2024). Maize (*Zea mays* L.) is an important species of the Poaceae family adapted to diverse environments in tropical and temperate regions of the world (Richard et al., 2021). Its grains are used for human and animal consumption and as a raw material for industry. It is native to the Americas and is cultivated in Africa, Central America, and other Asian countries. After rice and wheat, it is the most significant cereal in the world in terms of area and total production (Kaul et al., 2019), contributing 52% to the global human diet (FAO, 2019).

The species is salt intolerant (glycophyte), lacking the necessary biochemical mechanisms to cope with salt stress and unable to regulate the entry of ions into the xylem at salinity higher than 4 dS m^{-1} at advanced stages of development (Munns & Tester, 2008; Flowers & Colmer, 2015). As a result, the plant can experience a 50-80% decrease in productivity at salinity between 4-8 dS m^{-1} (Zörb et al., 2019).

Salt stress is a serious threat to agriculture because it significantly affects the growth, physiological functions, and yield of maize by negatively affecting various developmental stages, including seed germination, vegetative, and reproductive stages (Islam et al., 2024). However, little information is available on the conditioning of maize seeds with ultraviolet light under high salinity conditions, as most previous research has only analyzed the isolated effects of specific factors. Therefore, based on the hypothesis that exposure of seeds to UV-C radiation prior to germination could increase seedling tolerance to excess salt, the aim of this study was to evaluate the effect of conditioning maize seeds with UV-C light under salt-induced stress.

2 MATERIAL AND METHODS

For the physiological conditioning of the corn seeds, a box equipped with a 20 W UV-C lamp (Philips TUV 15WG15T8) was used, following the methodology adapted by Stefanello et al. (2023). The intensity of 2.5 W m^{-2} was measured in the central area with a radiometer (Lutron UV-C 254 model). The lamp was placed at a distance of 34 cm from the seeds. Exposure to UV-C light was at doses of 0.85 and 3.42 kJ m^{-2}, corresponding to 5.5 and 22.5 minutes, respectively. For comparison, unirradiated maize seeds were used as a control.

After conditioning at each UV-C dose, the maize seeds were spread on germination paper moistened with distilled water or saline solution (100 mM sodium chloride - NaCl). Paper rolls containing four replicates of 50 seeds each were prepared and kept in a germination chamber (25 ± 2 °C and 12 hours of light). The evaluations were carried out on the 4th (first count) and 7th days (germination), according to the method, which was adapted from Brasil (Ministério da Agricultura, Pecuária e Abastecimento, 2009).

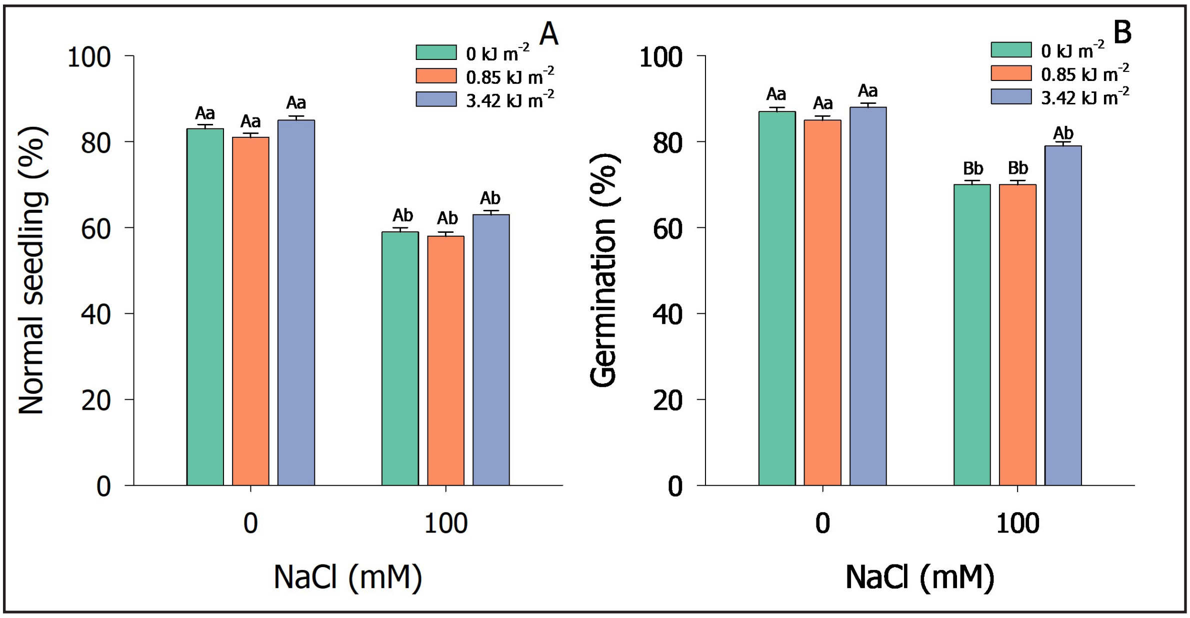
On the fourth day after sowing, the average seedling length (cm) was recorded using ten normal seedlings from each replicate. The ten seedlings were then placed in an oven at 60 ± 5 °C (for 48 hours) to dry the material, and the total dry mass was determined on a precision balance (0.001 g). The results were expressed in milligrams per seedling (Krzyzanowski et al., 2020).

The experimental design was completely randomized in a bi-factorial scheme, with treatments consisting of different doses of UV-C and NaCl. The Shapiro-Wilk and Bartlett tests were applied to verify the homogeneity of the variances and the normality of the residuals, respectively. The data that were collected were subjected to analysis of variance at the 5% probability level using Sisvar software version 5.6.

3 RESULTS AND DISCUSSION

The effects of salt stress and UV-C conditioning of corn seeds on germination and initial growth are shown in Figures 1-3. Compared to the control, the high salt concentration resulted in a reduction in the percentage of normal seedlings as assessed by the first count (83 to 59%, Figure 1A) and germination (87 to 70%, Figure 1B) tests. Application of UV-C (3.42 kJ m^{-2}) to salt-stressed seeds had a positive effect on germination compared to the control (non-irradiated seeds) (Figure 1B).

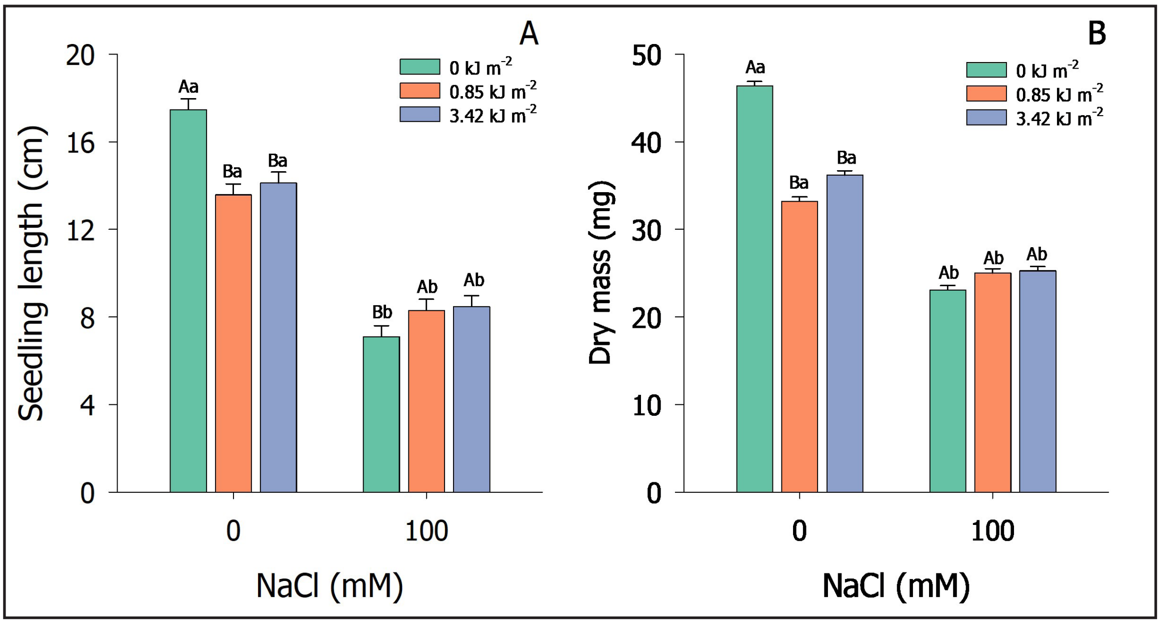
Figure 1 – Initial count (A) and germination (B) of maize seeds after conditioning in UV-C light in the absence of salt (0 mM NaCl) or high salt concentration (100 mM NaCl). *Capital letters indicate significant differences between UV-C doses within each NaCl concentration and lower case letters indicate significant differences between NaCl concentrations within the same UV-C dose. Criterion for significance ($p<0.05$)



Source: Authors (2024)

Besides the effect on seed germination, the increase in salinity negatively affected the growth of the seedlings, reducing their height from 17.47 cm to 7.10 cm and their dry mass from 46.40 mg to 23.07 mg (Figures 2A, 2B, and 3). These effects were alleviated in the growth of seedlings when they were simultaneously exposed to UV-C (0.85 or 3.42 kJ m^{-2}) and salt (Figure 2A).

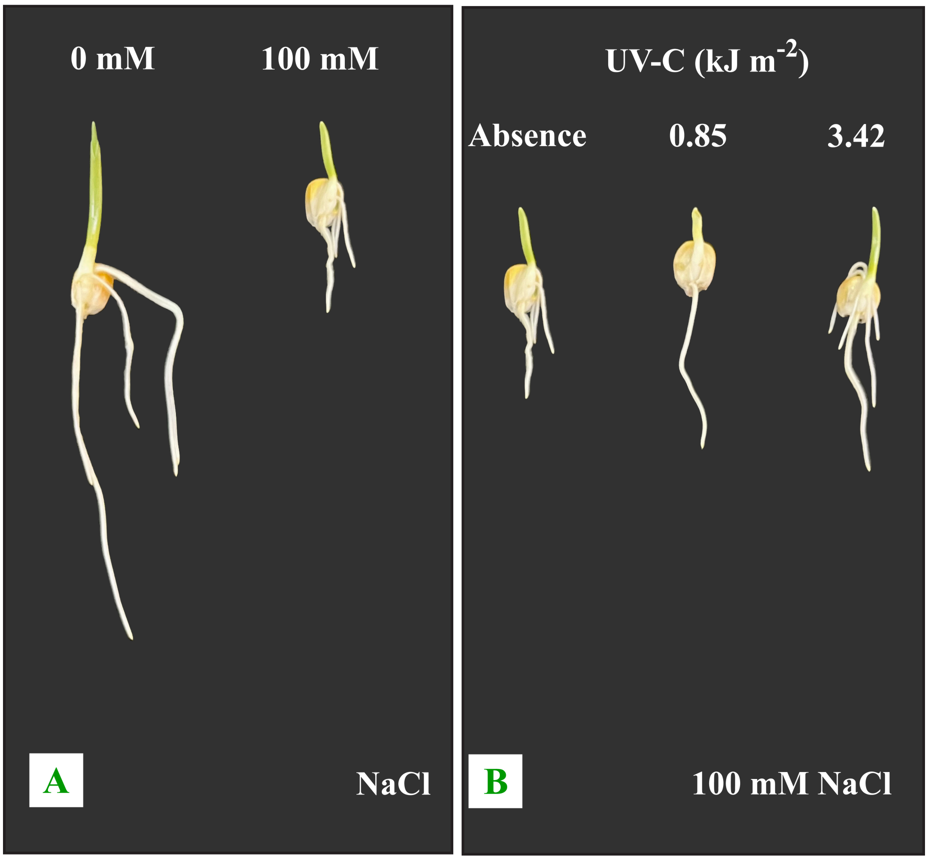
Figure 2 – Length (A) and dry mass (B) of maize seedlings after conditioning the seeds in UV-C light in the absence of salt (0 mM NaCl) or high salt concentration (100 mM NaCl). *Capital letters indicate significant differences between UV-C doses within each NaCl concentration and lower case letters indicate significant differences between NaCl concentrations within the same UV-C dose. Criterion for significance ($p<0.05$)



Source: Authors (2024)

The results of this research show that salt-induced stress resulted in a decrease in germination and initial growth of maize seedlings (Figures 1-3). Similar data were recorded in maize seeds, where an increase in osmotic potential (more negative) resulted in a lower germination rate (Amin et al., 2024) and reduced plant growth characteristics such as shoot and root length, root fresh and dry mass, leaf area, and chlorophyll content (Iftikhar et al., 2024). In addition, Khalid et al. (2023) reported that salt stress reduced the ratio of root to shoot length compared to the control, while Tian et al. (2024) found that germination rate, germination and salt tolerance index, seed vigor, radical length, and leaf area decreased with increasing salt concentration (up to 180 mM L^{-1}).

Figure 3 – (A) Schematic representation of maize seedlings in control (0) and 100 mM NaCl treatments. (B) Maize seedlings under salt stress (100 mM NaCl) after seed conditioning with UV-C light (0, 0.85, and 3.42 kJ m^{-2})



Source: Authors (2024)

Similarly, salt concentrations of 100 and 150 mM reduced the germination of maize seeds by 42.9% and 66.7%, respectively, compared to the control group (Barwal et al., 2024). In purple maize seeds, it was observed that the germination rate decreased with increasing salt concentration, with lower percentages recorded at 75 and 100 mM, in addition to a reduction in chlorophyll (total, a, and b) and total carotenoid content (Alves et al., 2022). On the other hand, in popcorn, salt stress affected both the physiological quality and the antioxidant activity of the seeds, as well as the performance of the seedlings (Catão et al., 2020).

When corn seeds or roots were exposed to salt, there was a reduction in seedling growth and root abnormalities, such as shortening, thickening, developmental changes, and necrosis. These results suggest that these changes may have occurred because the roots are the first organs of the seedling to encounter sodium and chlorine ions present in the substrate. As a result, there is a greater reduction in root growth compared to other parts of the seedling, such as the aerial part (Chen et al., 2023). The reduction in growth is related to the type of salt, the amount in the substrate, and the plant tissues impacted by the salt (Munns & Tester, 2008).

Obviously, the most important stages in a plant's growth process are germination and seedling development, which are influenced by both genetic and environmental factors. In many environments, the availability of water is a determining factor for seed germination and the success or failure of plant establishment (Abdellaoui et al., 2019). Thus, the presence of water is essential for germination. When plants face salt stress, the osmotic potential in plant cells becomes more negative due to the presence of a high salt concentration in the substrate, creating an osmotic gradient that expels water from the cells, reducing turgor pressure, and compromising root structure (Betzen et al., 2019; Sofy et al., 2021). The result is a reduction in the germination percentage, aerial and root growth, and seedling dry mass (Malik et al., 2022).

During the germination process, exposition to UV-C radiation (3.42 kJ m^{-2}) under salt stress has a beneficial effect on seeds (Figure 1B). In seedling growth, the protective effect of UV-C was observed at the two doses studied (0.85 and 3.42 kJ m^{-2}, Figure 2A). It can therefore be concluded that the conditioning of the seeds conferred a greater tolerance to salt stress.

Examining the same UV doses used in this study, Stefanello et al. (2024) found that white oat seedlings grown from UV-C-irradiated seeds showed greater tolerance to salt stress, with a more pronounced attenuating effect on germination at 0.85 kJ m^{-2}. Similarly, tomato seeds initially conditioned with UV-C light showed a reduction in the adverse effects of salt on physiological and biochemical analyses and, consequently, an improvement in plant growth (Alamer & Attia, 2022). In other studies, UV-C treatment of lettuce seeds (Ouhibi et al., 2014; Fgaier et al., 2023) and strawberry seeds (Xu et al., 2019) also resulted in greater resistance to salt, thus providing more effective plant protection.

Some studies suggest that faster and more uniform germination can be achieved by pre-treating seeds with low doses of UV-C light (Hossinifarahi et al., 2022; Atta et al., 2023). This procedure is considered an effective technique for treating seeds, as it improves their performance by addressing the negative effects of unfavorable conditions such as salinity (Hussain et al., 2018). In addition, exposing seeds to UV-C light during the early stages of germination can stimulate or induce acclimation mechanisms to abiotic stress in plants (Alamer & Attia, 2022). Thus, exposure of seeds to UV-C is an effective strategy to mitigate the deleterious effects of salt stress during germination and leaf and root development (Alamer & Attia, 2022; Atta et al., 2023).

The mechanism by which UV light acts on the physiological control of plants against salt-induced stress is influenced by several factors, such as the dose applied, the arrangement of the seeds, the duration of exposure, the developmental stage of the seedling, the power of the light source, the cultivar, and the intensity of the radiation (Forges et al., 2018; Hernandez-Aguilar et al., 2021; Alamer & Attia, 2022).

This study provides valuable insights into the ability of maize seedlings to tolerate UV-mediated salt stress. The results of this study corroborate other research suggesting that pre-exposure of seeds to UV-C light helps to mitigate the adverse effects of excess salt, particularly on the growth of maize seedlings.

4 CONCLUSIONS

Pre-exposure of maize seeds to UV-C radiation proved to be effective in mitigating the deleterious effects of excess salt on both seed germination (3.42 kJ m^{-2}) and seedling growth (0.85 and 3.42 kJ m^{-2}). Therefore, it can be concluded that the application of UV-C light to condition maize seeds may be a promising strategy to mitigate the adverse effects of high salt concentrations.

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