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EFFECTS OF ULTRAVIOLET-C (UV-C) RADIATION ON GERMINATION, SEEDLING GROWTH, AND ABIOTIC STRESS RESPONSE IN WAXY CORN (*Zea mays* L.)

Darwin A. Garbeles[1,*], Marygrace S. Milan[2], Dariel A. Palmiano[3]

[1]College of Science, Partido State University, Goa, Camarines Sur, Philippines 4422
[2]Department of Agriculture- Regional Field Office 5, Pili, Camarines Sur, Philippines 4418
[3]Central Bicol State University of Agriculture- Calabanga Campus, Calabanga, Camarines Sur, Philippines 4405

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ABSTRACT

Waxy corn (*Zea mays* L.) is an important crop in the Philippines, but its production has been hampered by various abiotic stresses, including waterlogging and salinity. This study investigates the potential of using UV-C radiation as a strategy to improve the growth performance of waxy corn under these stressful conditions. The study utilized a completely randomized design to evaluate the effects of different durations of 254 nm UV-C radiation (0, 30, 60, 90, & 120 min) on the germination and early seedling growth of waxy corn. Germination parameters and seedling growth under normal, waterlogged, and saline conditions were evaluated. The results showed that moderate UV-C exposure (30–60 minutes) had a beneficial effect on waxy corn seed germination, with significantly higher germination percentages and faster times to reach 50% germination compared to the control. However, longer exposure times (90–120 minutes) had a detrimental impact on germination. For seedling growth, moderate UV-C exposure (30–60 minutes) generally had a stimulatory effect, increasing various growth parameters under normal and waterlogged conditions. Longer exposure times (90–120 minutes) resulted in values closer to or not significantly different from the control. Under saline stress, increasing UV-C exposure time had a generally positive effect on seedling growth, with the optimal duration being around 90 minutes. The findings of this study suggest that the optimal duration of UV-C exposure for enhancing waxy corn germination and seedling growth varies depending on the specific environmental conditions. Moderate UV-C exposure (30–60 minutes) can be beneficial for improving seed germination and early seedling growth under normal and waterlogged conditions, while longer exposure times (> 90 minutes) are more suitable for enhancing growth under saline stress.

Keywords: radiation priming, saline, seed germination, seedling growth, waterlogged.

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[*]*Corresponding author email*: darwin.garbeles@parsu.edu.ph

INTRODUCTION

Waxy corn (*Zea mays* var *ceratina*) is an important cereal crop grown worldwide for its unique starch composition and versatile uses in food and industrial applications. The global production of waxy corn has steadily increased in recent years, driven by growing demand from the food and beverage industries (Foroughbakhch et al., 2019). In the Philippines, corn is a key staple crop that plays a vital role in the country's economy and food security (Parreño, 2023; Biñas, 2021; Urrutia et al., 2017). Despite the significance of waxy corn in the Philippines, the country's production has been hampered by various factors, including limited availability of high-quality seeds, inadequate crop management practices, and the prevalence of abiotic stresses. The Philippines' vulnerability to natural disasters, such as typhoons and flooding, has been a primary cause of decreased waxy corn productivity. Waterlogging and salinity are two major abiotic stresses that can severely affect the germination, growth, and yield of corn plants (Changjan et al., 2022; Ilagan et al., 2022; PSA, 2021).

One promising approach to enhance crop germination and abiotic stress tolerance properties is the use of Ultraviolet (UV) radiation. UV radiation has been shown to stimulate plant growth, improve stress tolerance, and enhance crop productivity in various plant species by the induction of the production of antioxidants, phytohormones, and other secondary metabolites that help plants cope with abiotic stresses (Foroughbakhch et al., 2019). One type of UV radiation is UV-C, with wavelengths shorter than visible light typically ranging from 100 to 280 nanometers (Kamel et al., 2022). However, there were no reported studies on the effect of UV-C radiation durations on enhancing waxy corn growth and abiotic stress tolerance.

Given the critical challenges faced by corn farmers, it is important to explore alternative cost-effective approaches that can enhance germination and abiotic stress tolerance in waxy corn. This research aims to investigate the potential of UV-C radiation as a strategy to improve the seed quality and resilience of waxy corn and contribute to the sustainability of the country's agricultural sector.

MATERIALS AND METHODS

Research design

This study utilized experimental research design, obtaining quantitative type of data. Samples for the germination test were randomly distributed and assigned using a Completely Randomized Design (CRD). For the growth and abiotic stress assays, a Youden square design ensured the randomization of the experimental setups. Finally, the study used a posttest-only control group design in the intervention application.

Experimental site

To ensure optimal conditions for investigating the effects of UV-C radiation on waxy corn, the study was conducted within the controlled environment of the Anatomy Laboratory at the Department of Biological Sciences, College of Science, Partido State University, Goa, Camarines Sur.

Plant material

Waxy corn (*Zea mays* L.) seeds were acquired from Pili, Camarines Sur, Philippines. Before initiating the experimental procedure, a germination test had been conducted to assess the viability of the seeds, which showed an acceptable germination percentage of 86.67%.

UV-C treatment

The corn seeds were first surface sterilized following the protocol reported by Thomas et al. (2020) and were then exposed to UV-C radiation following the protocols described by Foroughbakhch et al. (2019) and Aboul et al. (2014), with few modifications. Specifically, the corn seeds were soaked in 0.1% (w/v) mercuric chloride (HgCl2) solution for 5 minutes and then washed thoroughly with distilled water. The surface-sterilized seeds were placed in sterile 90 mm Petri dishes, with 40 seeds per dish. They were then exposed to 254 nm UV-C radiation at an intensity of 2.5 W/m^2 from an artificial source (Philips TUV 15WG15T8) for different durations: 0

(Control), 30, 60, 90, and 120 minutes. This range of UV-C exposure times served as the treatment groups to assess the effects of UV-C radiation on the waxy corn seeds.

Germination test

A germination test was carried out to determine the effect of different durations of exposure to 254 nm UV-C radiation on the germination process of waxy corn. This followed the procedures outlined by Sadeghi et al. (2011) with a few modifications in accordance with the protocol described by Meena et al. (2016). A total of 30 UV-C exposed seeds per exposure duration were aseptically distributed to 3 replicates, with 10 seeds placed in sterile 90 mm Petri dishes. A seed was considered germinated when the radicle had emerged and pierced the seed coat up to a length of 2mm. The germination test evaluated several key parameters, including Germination Percentage (G%), Germination Time represented as "Time to reach 50% germination (T50)", and Germination Index (GI). Germination percentage was calculated by counting the total number of germinated seeds, dividing by the total number of seeds sown, and multiplying by 100. The time required to reach 50% germination was determined using the Logit model of regression, following the protocol outlined by Jardim et al. (2021), with the formula "$y = e(b_0 + b_1X)/1+e(b_0 + b_1X)$". In this formula, *X* represents the input value, *y* is the predicted output, b_0 is the bias or intercept term, b_1 is the coefficient for the input (*x*), and *e* is the base of natural logarithms. The germination index was calculated according to the equation "GI= (No. of germinated seeds/days of the first count) +…..+ (No. of germinated seeds/ days from the first count)".

Seedling growth and abiotic stress-response evaluation

The seedling growth evaluation was carried out to determine the effect of different time of exposure to 254 nm UV-C radiation on the early growth performance of waxy corn under normal, waterlogged and saline conditions. This followed the procedures of Bakhshandeh et al. (2017) and Boubekri et al. (2021) with few modifications. A total of 30 UV-C exposed seeds per treatment were distributed to three (3) replicates, with 10 seeds placed in germination trays filled with two-thirds of sterile and nutrient-rich soil. The UV-C radiated corn seeds were allowed to germinate at laboratory conditions (25 ± 2 ^{o}C, 70 ± 5% relative humidity, and 11/13 h light/dark photoperiod). For the treatment groups under waterlogging stress, 150 mL of distilled water was added to each experimental unit every other day until the experiment was terminated. For the treatment groups under salinity stress, 3.89 g of NaCl were added to 100 g of soil samples with an initial electrical conductivity (EC) of 0.181 dS/m to induce salinity. This resulted in a slightly saline soil condition of ~ 6 dS/m, based on the linear relationship between EC and NaCl concentration (Rhoades, 1996; Corwin & Lesch, 2005; Widodo et al., 2018).

The seedlings were uprooted on the 10th day after sowing, and early seedling growth parameters were recorded, including shoot length, leaf length, root length, and root and shoot fresh weight. Shoot length was measured from the base of the corn seedling to the base of the emerging leaf. Leaf length was assessed by measuring the length of the longest emerging leaf from the base where it emerged from the stem to the tip of the leaf blade. Root length was measured by carefully uprooting the corn seedlings and measuring the longest root from the base to the tip. Finally, the shoots and roots of the corn seedlings were separately weighed using an analytical balance to obtain their fresh weights.

Data analysis

The data collected during the study was summarized as the means of replicates ± standard error of the means (SE). It was then statistically analyzed using the One-way Analysis of Variance (ANOVA) procedure, followed by Tukey's Test for multiple comparisons. This analysis was carried out utilizing the IRRI- Statistical Tool for Agricultural Research (STAR) version 2.0.1

software, at a significance level of p ≤ 0.05. Furthermore, treatment mean differences were represented as percent (%) change utilizing the formula: Percent Change = (Final value-Initial value)/Initial Value × 100.

RESULTS

Effect of UV-C radiation on germination performance

This study investigated the impact of varying durations of UV-C radiation exposure on the germination performance of waxy corn seeds. Waxy corn seeds were subjected to 254nm UV-C radiation treatments, from 0 minutes (control) to 120 minutes, with 30-minute increments between treatments. The germination parameters evaluated included germination percentage, germination time, and germination index. The data obtained from the experiment (Table 1) indicates that the corn seeds exposed to 254nm UV-C radiation demonstrated varied germination percentage depending on the duration of exposure. Seeds exposed for 30 minutes and 60 minutes both achieved the highest germination rate of 100%. Meanwhile, the group of seeds exposed to UV-C radiation for 90 minutes had a slightly lower germination rate of 93.33 ± 3.33%. Furthermore, the seeds exposed to UV-C radiation for 120 minutes obtained the lowest germination percentage recorded at 66.67 ± 3.33%. Based on the result of the germination test, it can be noticed that the corn seeds exposed for 30 and 60 minutes obtained significantly (*p* = 0.29) higher germination percentage than the control group, showing a 13.33% improvement on germination percentage. In contrast, the longer exposure times of 90 and 120 minutes begin to have a more detrimental impact on germination success with the 120-minute group showing a significant (*p* = 0.02) 20.00% decrease in germination percentage, implying that excessive UV-C exposure can reduce the germination percentage and may be detrimental to corn seed.

Table 1. Effect of UV-C exposure duration on germination performance of waxy corn (*Zea mays* L.)

Exposure time (min)	Germination percentage (%)	Germination time at 50% (days)	Germination index
0	86.67 ± 3.33%	1.93 ± 0.05	6.06 ± 0.24
30	100.00 ± 0.00%*	1.81 ± 0.15	7.00 ± 0.67
60	100.00 ± 0.00%*	1.42 ± 0.07	9.33 ± 0.50
90	93.33 ± 3.33%	1.49 ± 0.18	8.78 ± 1.26
120	66.67 ± 3.33%*	2.21 ± 0.08	5.56 ± 0.98

Note: Mean ± Standard Error (SE); * = significant vs. control group ($p < 0.05$); n = 3.

The data presented in Table 1 shows that corn seeds exposed to 60 min UV-C radiation obtained the fastest time to reach 50% germination, at 1.42 ± 0.07 days, 26.43% faster than the unexposed corn seeds. The 90-minute UV-C exposure group had the next fastest time to 50% germination, at 1.49 ± 0.18 days, followed by the 30-minute group at 1.81 ± 0.15 days. In contrast, the seeds exposed to UV-C radiation for 120 minutes took the longest time to reach 50% germination, at 2.21 ± 0.08 days, or 14.51% slower than the negative control group. In terms of germination index, it can be observed that the 60-minute UV-C exposure group obtained the highest germination index recorded at 9.33 ± 0.50, which represents a 53.96% improvement compared to the negative control group with a germination index of 6.06 ± 0.24. Followed by the corn seeds exposed to 90 min UV-C radiation with a germination index of 8.78 ± 1.26 and the 30-minute UV-C exposure group with 7.00 ± 0.67. Moreover, it can also be noted that the seeds exposed to UV-C radiation for 120 minutes obtained the lowest germination index of 5.56 ± 0.98, which was 8.25% lower than the negative control group. Despite these observed differences in germination time and index, the statistical analysis revealed that there were no significant differences ($p > 0.05$) between the control group and the treatment groups. This suggests that the observed variations in germination time and index were not statistically significant and that the UV-C radiation exposure did not have a direct, statistically significant effect on the germination time of waxy corn seeds.

Effect of UV-C radiation on seedling growth

The effect of varying UV-C radiation exposure duration on the early seedling growth of waxy corn under normal condition was analyzed in this study. Waxy corn seedlings were exposed to varying durations of UV-C radiation at 254 nm, ranging from 30 to 120 minutes, and their growth parameters including shoot length, shoot weight, shoot diameter, leaf length, root length, and root weight were measured. These measurements were then compared to those of control seedlings that were not exposed to any radiation.

The results (Table 2) show that the different exposure time on UV-C radiation had a significant impact on various growth parameters of the waxy corn seedlings compared to the control group (0 minutes exposure). At 30 minutes of UV-C exposure, the seedlings showed a significant ($p < 0.05$) increase in shoot diameter (35.37%), and leaf length (17.38%) compared to the control. Exposure to 60 minutes of UV-C radiation resulted in a significant ($p < 0.05$) increase in shoot length (16.65%), and leaf length (20.71%) compared to the control. The 90-minute UV-C exposure also led to a significant ($p < 0.05$) increase in shoot length (12.15%), and leaf length (18.94%) compared to the control. However, at the longest exposure time of 120 minutes, the seedling growth parameters generally decreased compared to the shorter exposure times.

Table 2. Effect of UV-C radiation exposure duration on waxy corn seedling growth

ET (min)	SL (cm)	SW (g)	SD (mm)	LL (cm)	RL (cm)	RW (g)
0	9.55 ± 0.17	0.99 ± 0.03	2.29 ± 0.20	20.43 ± 0.95	17.84 ± 0.59	0.53 ± 0.02
30	10.35 ± 0.18	1.01 ± 0.02	3.10 ± 0.47*	23.98 ± 0.54*	16.98 ± 1.18	0.61 ± 0.03
60	11.14 ± 0.26*	1.18 ± 0.10	2.60 ± 0.15	24.66 ± 0.74*	19.66 ± 0.78	0.68 ± 0.03
90	10.71 ± 0.22*	1.04 ± 0.06	2.70 ± 0.15	24.30 ± 0.74*	19.38 ± 1.65	0.62 ± 0.01
120	10.41 ± 0.07	0.85 ± 0.08	2.58 ± 0.23	22.97 ± 0.43	16.26 ± 0.56	0.56 ± 0.07

Note: Mean ± SE; ET = exposure time; SL = shoot length; SW = shoot weight; SD = shoot diameter; LL = leaf length; RL = root length; RW = root weight; * = significant vs. control group ($p < 0.05$); n = 3.

In terms of shoot growth, there was a stimulatory effect on shoot length, shoot weight, and shoot diameter with exposure durations up to 60 minutes. Seedlings exposed to 30 and 60 minutes of UV-C radiation showed significant increases in these parameters compared to the control group. However, exposure for 120 minutes resulted in values statistically similar to the control group for shoot length and weight, suggesting a possible inhibitory effect at higher durations of UV-C radiation exposure. Moreover, in terms of leaf length, it showed similar results to shoot growth, which showed a positive response to UV-C exposure up to 60 minutes, with significant increases compared to the control. Exposure for longer durations (90 and 120 minutes) resulted in values closer to the control group, suggesting a potential diminishing effect at higher exposures. Finally, for the effect on the root system, Root length did not show a clear trend. While 30-minute exposure had a slight decrease, exposure durations between 60 and 90 minutes maintained a similar root length to the control. Root weight showed a slight increase with all exposure durations compared to the control, but only statistically significant for the 60-minute treatment.

Abiotic stress response of UV-C radiated corn

This study evaluated the early growth response of corn exposed to UV-C radiation under waterlogging and saline conditions. The data presented in Figure 1 shows the growth response of corn seeds subjected to different durations of 254 nm UV-C radiation exposure under waterlogged and saline stress conditions. For waterlogged, the shoot length significantly (p = 0.0004) increased from 8.24 ± 0.30 cm at 0 minutes exposure to a peak of 11.91 ± 0.6 cm at 60 minutes exposure. However, after 60 minutes, the shoot length decreased, reaching 9.36 ± 0.54 cm at 120 minutes exposure. In contrast, the shoot length under saline condition significantly (p = 0003) increased steadily from 8.83 cm at 0 minutes to 12.67 cm at 120 minutes exposure. Unlike in the waterlogged condition, the UV-C radiated corn under saline condition continued to increase even after 60 minutes, indicating that corn plants can tolerate high salinity once exposed to a higher duration of UV-C exposure.

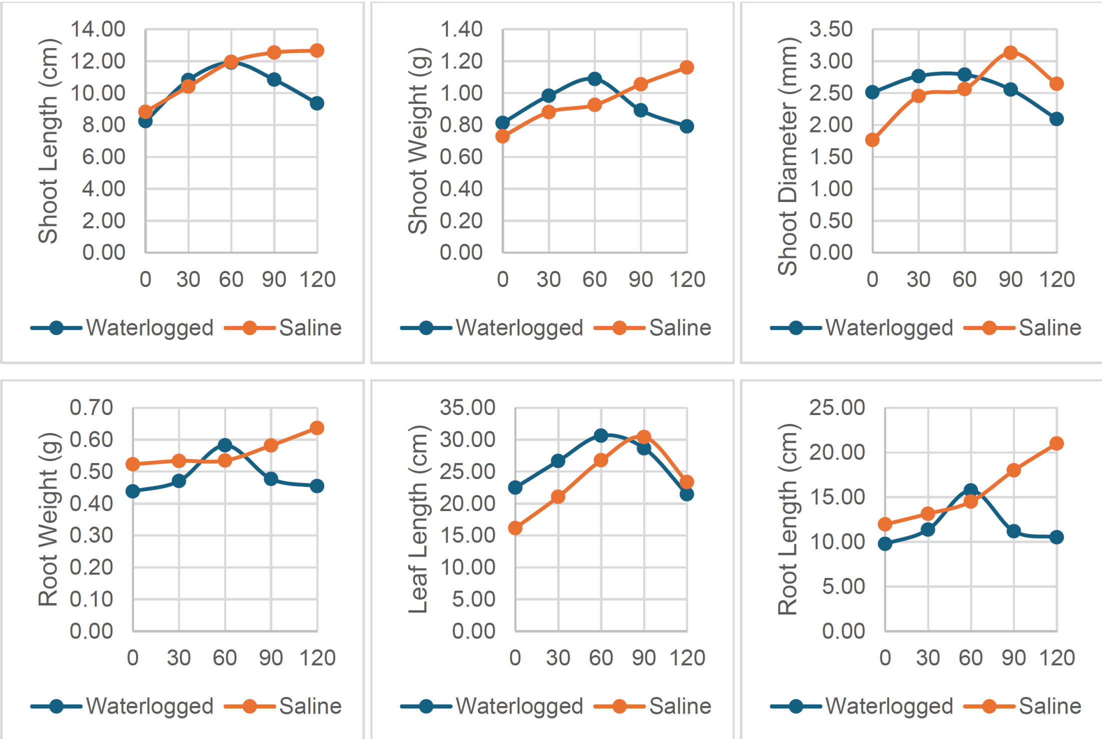

Figure 1. Effect of UV-C exposure duration on the abiotic stress response of corn

Under waterlogged stress, the shoot weight of corn increased from 0.81 ± 0.10 g at 0 minutes to a peak of 1.09 ± 0.07 g after 60 minutes of UV-C exposure. However, further increases in UV-C exposure time led to a decrease in shoot weight, with the value at 120 minutes dropping to 0.79 ± 0.09 g, which is lower than the initial weight at 0 minutes. In contrast, under saline stress, the shoot weight of corn increased steadily with longer UV-C exposure times. By 120 minutes of UV-C exposure, the shoot weight reached a peak of 1.16 ± 0.10 g, reflecting a 58.9% increase from the initial weight of 0.73 ± 0.05 g at 0 minutes. A similar trend was observed in shoot diameter development. At 0 minutes of UV-C exposure, the shoot diameter under waterlogged stress was measured at 2.51 ± 0.03 mm, while the saline shoot diameter was 1.77 ± 0.06 mm. As UV-C exposure time increased, the shoot diameter under waterlogged stress initially rose, reaching a maximum of 2.79 ± 0.71 mm at 60 minutes, before declining to 2.09 ± 2.01 mm at 120 minutes. Conversely, under saline stress, the shoot diameter continued to increase with UV-C exposure time, peaking at 3.13 ± 0.22 mm after 90 minutes of UV-C exposure, and then slightly decreasing to 2.65 ± 0.08 mm at 120 minutes of UV-C exposure.

In terms of leaf development, under waterlogged stress, the leaf length initially increased as the UV-C exposure time increased, reaching a maximum of 30.63 ± 1.12 cm at 60 minutes of exposure. However, after 90 minutes of UV-C exposure, the leaf length started to decrease, reaching 21.47 ± 1.47 cm at 120 minutes of exposure. This suggests that moderate UV-C exposure (up to 60 minutes) can have a beneficial effect on the growth of corn plants under waterlogged stress, but prolonged exposure (beyond 90 minutes) may be detrimental. Under saline stress, the leaf length steadily increased significantly (p = 0.00001) as the UV-C exposure time increased, reaching a maximum of 30.42 ± 0.82 cm at 90 minutes of exposure. At 120 minutes of UV-C exposure, the leaf length decreased to 23.38 ± 0.97 cm. This indicates that increasing UV-C exposure time has a generally positive effect on the growth of corn plants under saline stress, with the optimal duration being around 90 minutes.

In terms of root length, it can be observed that at 0 minutes of UV-C exposure, the root length under waterlogged stress was 9.77 ± 0.27 cm, and under saline stress, it was 11.96 ± 0.43 cm. As the UV-C exposure time increased to 30 minutes, the root length increased to 11.38 ± 1.10 cm under waterlogged stress, indicating a positive response to UV-C treatment. The root length significantly (p = 0.24) peaked at 60 minutes of UV-C exposure, reaching 15.74 ± 1.00 cm under waterlogged conditions, suggesting that this duration provided the optimal UV-C treatment. However, further increases in UV-C exposure time to 90 and 120 minutes led to a decrease in root length, with values of 11.19 ± 0.76 cm and 10.52 ± 1.85 cm, respectively, indicating that prolonged UV-C exposure may have a detrimental effect. Under saline stress conditions, the root length increased as the UV-C exposure time increased, reaching 13.14 ± 0.83 cm at 30 minutes, 14.51 ± 1.40 cm at 60 minutes, and 18.00 ± 2.85 cm at 90 minutes. The maximum root length was observed at 120 minutes of UV-C exposure, with a significant (p = 0.034) value of 21.00 ± 1.38 cm, suggesting that prolonged UV-C treatment may be beneficial for corn growth under saline stress. A similar growth pattern was observed in root weight. Under waterlogged stress, root weight increased from 0.44 g to a peak of 0.58 g after 60 minutes of UV-C exposure, showing a 32% increase. However, after a UV-C exposure duration of 60 minutes, root weight decreased, dropping to 0.45 g at 120 minutes exposure. This suggests that 60 minutes of UV-C exposure provided the optimal stimulation of root growth under waterlogged conditions, and longer exposures became detrimental. In contrast, under saline stress, root weight increased steadily from 0.52 g to 0.64 g after 120 minutes of UV-C exposure, indicating a 23% increase. Unlike under waterlogged stress, the maximum exposure time of 120 minutes continued to enhance root growth under saline conditions.

DISCUSSION

Effect of UV-C exposure duration on germination performance

The research findings indicate that the impact of UV-C radiation at 254 nm on the germination and growth of waxy corn seeds is dependent on the duration of exposure. Moderate durations of UV-C radiation, in the range of 30–60 minutes, were found to have a beneficial impact on the germination of waxy corn seeds. These exposure durations resulted in significantly higher germination percentages, faster germination time, and improved germination index compared to the control group. In contrast, longer durations of UV-C radiation, such as 90 and 120 minutes, began to have a detrimental impact on the corn seeds. These exposure durations showed a significant decrease in germination percentage, slower germination time, and reduced germination index compared to the control group.

A study investigating the effects of UV-C radiation on maize and sugar beet seeds has revealed notable patterns. While germination percentages were not significantly impacted by UV-C exposure at 254 nm, longer exposure durations specifically 8 to 12 hours led to improved germination rates (Sadeghianfar et al., 2019). This finding suggests that while extended exposure can enhance certain aspects of germination, there may be a threshold beyond which negative effects begin to emerge, similar to the results of this study. Similar trends have been observed in other crops, including soybean and rice. Research indicates that exposure to UV-B (280-320nm) and UV-C (254 nm) radiation can yield both beneficial and detrimental effects on seed germination. For instance, excessive UV-B and UV-C exposure (>1hr) has been shown to decrease germination percentages in soybeans (Stefanello et al., 2023; Huyuan et al., 2001). Conversely, moderate durations (≤ 1 hr) of UV-C radiation can enhance germination and promote early seedling growth in rice; however, prolonged exposure tends to have adverse effects (Mutum et al., 2024; Panwar, 2019).

The improvement in germination performance of seeds subjected to UV-C radiation can be attributed to its ability to induce the accumulation of beneficial secondary metabolites, such as flavonoids and saponins, in the seed coat and increased concentrations of reactive oxygen species (ROS) and an increase in temperature after exposure to UV-C radiation (Guajardo-Flores et al., 2014; Sadeghianfar et al., 2019). This accumulation of beneficial secondary metabolites can help protect the seeds from various environmental stresses, such as oxidative stress, pathogen attack, and UV radiation itself. Additionally, reactive oxygen species (ROS), generated during UV-C exposure can trigger adaptive responses in seeds, enhancing their ability to withstand stressors while promoting higher oxygen and water imbibition. This process not only facilitates improved germination rates but also alleviates seed dormancy. Furthermore, the rise in temperature following UV-C exposure contributes significantly to enhanced germination performance by accelerating metabolic processes, such as seed respiration and mitochondrial activity, thereby promoting seed activation.

Effect of UV-C exposure duration on seedling growth

This research indicates that UV-C radiation at 254 nm can stimulate early seedling growth in waxy corn, with the effect influenced by exposure duration. Short exposures of 30–60 minutes generally resulted in significant improvements in shoot growth parameters compared to the control group, suggesting that this duration positively affects early seedling development. The observed stimulatory effects from moderate UV-C exposure are hypothesized to stem from activated defense mechanisms and growth-promoting pathways. UV-C radiation may induce reactive oxygen species, which serve as signalling molecules triggering adaptive responses in seedlings (Lazim & Nasur, 2017; Foroughbakhch et al., 2019). This observation can also be associated with the modulation of gene expression related to photomorphogenesis and stress responses. For instance, genes such as COP1 and HY5 are implicated in regulating plant responses to light and stress, suggesting a complex interplay between light perception and UV-induced signalling pathways (Boycheva et al., 2021). Conversely, longer exposure times of 90–120 minutes yielded growth results similar to the control, indicating a potential inhibitory effect at higher UV-C doses. The lack of growth response at higher doses may be attributed to increasing cellular damage or stress responses that overwhelm the adaptive benefits. The enormous increase in reactive oxygen species (ROS) may trigger the activation of antioxidant mechanisms, which can divert resources away from growth processes toward defense responses. This shift is evident in the enhanced activity of antioxidant enzymes like catalase, which helps mitigate oxidative damage but may also contribute to reduced growth rates (Sarghein et al., 2011; Abrun et al., 2016).

In terms of root growth, responses were more variable than those observed in shoots. A 30-minute UV-C exposure resulted in a slight decrease in root length but an increase in root weight. Longer exposure durations of 60–90 minutes resulted in root lengths that were statistically similar to the control group. This variability suggests that while moderate UV-C doses may enhance shoot growth, root responses are more complex. The increase in root weight despite the slight length reduction with a 30-minute exposure may indicate a shift in resource allocation, prioritizing root thickening over elongation under specific UV-C conditions (Hammok, 2019; Gao-zhan, 2007). Moreover, in a study with *Allium cepa*, Çavuşoğlu et al. (2022) reported that treatments with UV-C light (254 nm) caused a similar effect on root parameters, suggesting that exposure to UV-C radiation triggered growth inhibition, cytogenotoxicity, and damage to meristematic cells in the roots.

Effect of UV-C exposure duration on abiotic stress response

Waxy corn plants exposed to UV-C radiation exhibited improved tolerance to saline stress. As the duration of UV-C exposure increased, the plants showed a steady increase in shoot length and diameter, reaching their peak values by the end of the experiment. Additionally, root length and weight were enhanced under saline conditions when the plants were subjected to UV-C radiation, indicating that corn can benefit from high salinity levels when exposed to 254 nm UV-C radiation for extended periods. These findings are consistent with research conducted on other crops, such as lettuce and tomato, where UV-C priming has been shown to enhance photosynthetic efficiency and growth under saline conditions. Specifically, studies have indicated that UV-C exposure improves leaf net photosynthetic assimilation and total photosynthetic electron transport rates, even in the presence of elevated salinity (Alamer & Attia, 2022; Fgaier et al., 2023). Furthermore, the positive response of corn in saline environments may be linked to the role of phytohormones in mediating plant responses to salinity stress. UV-C priming appears to increase concentrations of salicylic acid (SA) and cytokinins (CKs) while maintaining stable levels of abscisic acid (ABA) and auxin. This hormonal balance is critical for enhancing stress tolerance, as SA is known to stimulate antioxidant activity, thereby safeguarding the photosynthetic apparatus from damage caused by reactive oxygen species (ROS) generated during stress conditions. In contrast, the response of UV-C exposed seeds in waterlogged conditions revealed a more nuanced outcome. Initial growth stimulation was observed up to 60 minutes of UV-C exposure, after which both shoot and root lengths began to decline by 120 minutes. This trend indicates that while moderate exposure to UV-C can be beneficial for corn growth in waterlogged environments, prolonged exposure may lead to detrimental effects. The combination of UV-C radiation and waterlogging may exacerbate the stress on plants. UV-C can cause oxidative damage to plant cells, while waterlogging reduces the plant's ability to cope with stress due to the reduction of oxygen availability in the root zone, leading to decreased nutrient and water uptake (Khan et al., 2023; Tahjib-Ul-Arif et al., 2023; Zhang et al., 2023).

CONCLUSION

Based on the findings of this study, the optimal duration of 254 nm UV-C exposure for enhancing corn growth and performance varies depending on the specific environmental conditions and the growth stage being evaluated. For seed germination, moderate durations of 254 nm UV-C radiation in the range of 30–60 minutes were found to be beneficial, with seeds exposed for 30 and 60 minutes achieving the highest germination rates and a significant improvement in the germination index compared to the control group. However, longer exposures of 90–120 minutes have a detrimental impact, resulting to a decreased germination percentage. A similar trend was observed for early seedling growth, where shorter UV-C exposure times of 30–60 minutes generally had a stimulatory effect, increasing various growth parameters compared to the control. Longer exposure times of 90–120 minutes resulted in growth values closer to or not significantly different from the control, suggesting a potential inhibitory effect at higher UV-C exposure duration. Under waterlogged stress, the growth parameters initially increased with UV-C exposure, peaking at 60 minutes, and then decreased with longer exposure. In contrast, under saline conditions, the corn plants exhibited a clear preference for extended UV-C exposure, with various growth parameters increasing steadily with increasing UV-C exposure time, reaching maximum values at 120 minutes.

REFERENCES

Aboul Fotouh M., Guindi F., El-Naggar H. A., Tag El-Din M., Sharaf Eldeen H., 2014. Influence of seed treatment with UV-C on saline stress tolerance in green beans (*Phaseolus vulgaris* L.). *J. Biol Chem Environ Sci*, 9: 391–414.

Abrun A., Fattahi M., Hassani A., Avestan S., 2016. Salicylic Acid and UV-B/C Radiation Effects on Growth and Physiological Traits of *Satureja hortensis* L. *Notulae Scientia Biologicae*, *8*(2), 170–175. https://doi.org/10.15835/nsb829784

Alamer K. H., Attia H., 2022. UV-C seed priming improves tomato plant growth against salt stress. *Journal of Taibah University for Science*, 16(1): 1181–1191. https://doi.org/10.1080/16583655.2022.2153443

Bakhshandeh E., Pirdashti H., Lendeh K. S., 2017. Phosphate and potassium-solubilizing bacteria effect on the growth of rice. *Ecological Engineering*, 103: 164–169. doi: 10.1016/j.ecoleng.2017.03.008

Biñas E. J., 2021. The Use of Organic and Inorganic fertilizers and its Effect on the Quality of Corn Products in the Philippines: A Review. *Galaxy International Interdisciplinary Research Journal*, 9(05): 83–100. https://doi.org/10.17605/OSF.IO/PUC7A

Boubekri K., Soumare A., Mardad I., Lyamlouli K., Hafidi M., Ouhdouch Y., Kouisni L., 2021. The screening of potassium-and phosphate-solubilizing actinobacteria and the assessment of their ability to promote wheat growth parameters. *Microorganisms*, 9(3): 470. https://doi.org/10.3390/microorganisms9030470

Boycheva I., Georgieva R., Stoilov L., Manova V., 2021. Effects of light and UV-C radiation on the transcriptional activity of COP1 and HY5 gene homologues in barley, Mutation breeding, genetic diversity and crop adaptation to climate change. Wallingford UK: CABI, pp. 478–486. https://doi.org/10.1079/9781789249095.0049

Çavuşoğlu K., Kalefetoğlu-Macar T., Macar O., 2022. Comparative investigation of toxicity induced by UV-A and UV-C radiation using *Allium* test. *Environ Sci Pollut Res*, 29: 33988–33998. https://doi.org/10.1007/s11356-021-18147-1

Changjan D., Toyen D., Umroong P., 2022. Effect of UV-C Radiation on Seed Germination and Some Ultrastructure in Water Convolvulus (*Ipomoea aquatica* Forssk. 'Reptan'). *Microsc. Microanal. Res*., 35: 33–37.

Corwin D. L., Lesch S. M., 2005. Characterizing soil spatial variability with apparent soil electrical conductivity: I. Survey protocols. *Computers and Electronics in Agriculture*, 46(1–3): 103–133. doi: 10.1016/j.compag.2004.11.002

Cosentino C., Paolino R., Adduci F., Tarricone S., Pacelli C., Sabia E., Freschi P., 2023. Case Study on the Impact of Water Resources in Beef Production: Corn vs. Triticale Silage in the Diet of Limousine × Podolian Young Bulls. *Animals (Basel*), 13(21): 3355. https://doi.org/10.3390/ani13213355

Fgaier S., Aarrouf J., Lopez-Lauri F., Lizzi Y., Poiroux F., Urban L., 2023. Effect of high salinity and of priming of non-germinated seeds by UV-C light on photosynthesis of lettuce plants grown in a controlled soilless system. *Frontiers in plant science*. https://doi.org/10.3389/fpls.2023.1198685

Foroughbakhch P. R., Bacópulos M. E., Benavides M. A., Salas C. L., Ngangyo H. M., 2019. Ultraviolet Radiation Effect on Seed Germination and Seedling Growth of Common Species from Northeastern Mexico. *Agronom*y, 9(6): 269. https://doi.org/10.3390/agronomy9060269

Furianto P., Budiari S., Muda E. V., Mulyani H., Maryati Y., Handayani N.A., Melanie H., Devi A. F., Artanti N., Susilowati A., Aspiyanto A., Filailla E., Sugiwati S., 2024. The Influence of Soaking Condition and Germination on Antioxidant Activity, and Chemical Properties of White Waxy Corn. *E3S Web of Conferences*. https://doi.org/10.1051/e3sconf/202450305002

Gao-zhan Q., 2007. Effects of short-term interrupted and continuous UV-C radiation on growth and physiology of pepper seedlings. *Journal of Northwest A & F University*.

Guajardo-Flores D., Serna-Guerrero D., Serna-Saldívar S., Jacobo-Velázquez D., 2014. Effect of Germination and UV-C Radiation on the Accumulation of Flavonoids and Saponins in Black Bean Seed Coats. *Cereal Chemistry*, 91: 276–279. https://doi.org/10.1094/CCHEM-08-13-0172-R

Hammok, N. S., 2019. Toxic Effect of Pendimethalin and UV-C Radiation on Germination and Corn Growth *Zea mays* L Seedling. *Proceedings of the 6th Int. Conf. Biotech., Environ. Engg. Sci. (ICBE6)*.

Huyuan F., Shijian X., Lizhe A., Zhijie L., Xunling W., 2001. Effects of increased UV-B radiation on seed germination and seedlings growth of eight cultivars of *Glycine max*. *Acta Botanica Boreali-occidentalia Sinica,* 21(1): 14–20.

Ilagan C. M. A., Binamira J. S., Navarro R. V., 2022. Philippine yellow corn industry roadmap (2021–2040). https://www.da.gov.ph/wp-content/uploads/2023/05/Philippine-Yellow-Corn-Industry-Roadmap.pdf; accessed 03/06/2024.

Kamel R. M., El-kholy M. M., Tolba N. M., 2022. Influence of germicidal ultraviolet radiation UV-C on the quality of Apiaceae spices seeds. *Chem. Biol. Technol. Agric*., 9: 89. https://doi.org/10.1186/s40538-022-00358-4

Khan F., Siddique A. B., Shabala S., Zhou M., Zhao C., 2023. Phosphorus Plays Key Roles in Regulating Plants' Physiological Responses to Abiotic Stresses. *Plants (Basel, Switzerland)*, 12(15): 2861. https://doi.org/10.3390/plants12152861

Lazim S. K., Nasur A., 2017. The effect of magnetic field and ultraviolet-C radiation on germination and growth seedling of sorghum (*Sorghum bicolor* L. Moench). *IOSR Journal of Agriculture and Veterinary Science* (IOSR-JAVS), 10: 30–36.

Meena S. K., Rakshit A., Meena V. S., 2016. Effect of seed bio-priming and N doses under varied soil type on nitrogen use efficiency (NUE) of 72 wheat (*Triticum aestivum* L.) under greenhouse conditions. *Biocatalysis and agricultural biotechnology*, 6: 68–75. doi: 10.1016/j.bcab.2016.02.010

Mutum B., Bera K., Chaudhury K. M., Dutta P., 2024. Impact of Priming with UV Radiation on Seed Germination and Seedling Growth of Chakhao Rice Cultivar. *Int. Journal of Plant & Soil Science.* doi: 10.9734/ijpss/2024/v36i24364

Panwar D., 2019. Mitigatory Effects of Plant Growth Regulators Over UV-B Radiation Damage on Productivity and Biomass in Rice Crop. *International Journal of Engineering Research & Technology*.

Parreño S. J. E., 2023. Forecasting Quarterly Rice and Corn Production in the Philippines: A Comparative Study of

Seasonal Arima and Holtwinters Models. *ICTACT Journal on Soft Computing*, 14(2).

PSA (Philippine Statistics Authority), 2021. Statistics on yellow corn wholesale prices. http://psa.gov.ph/; accessed 04/06/2024.

Rhoades J. D., 1996. Salinity: Electrical conductivity and total dissolved solids., D. L. Sparks (Ed.), Methods of Soil Analysis Part 3: Chemical Methods. SSSA, Madison, WI, USA, pp. 417–435. https://doi.org/10.2136/sssabookser5.3.c14

Romeiko X. X., Guo Z., Pang Y., Lee E. K., Zhang X., 2020. Comparing Machine Learning Approaches for Predicting Spatially Explicit Life Cycle Global Warming and Eutrophication Impacts from Corn Production. *Sustainability*, 12(4): 1481. doi: 10.3390/su12041481

Rupiasih N. N., Vidyasagar P. B., 2016. Effect of UV-C radiation and hypergravity on germination, growth and content of chlorophyll of wheat seedlings. *Proceedings of the AIP conference*, 1: 1719. https://doi.org/10.1063/1.4943730

Sadeghi H., Khazaei F., Yari L., Sheidaei S., 2011. Effect of seed osmopriming on seed germination behavior and vigor of soybean (*Glycine max* L.). *ARPN Journal of Agricultural and Biological Science*, 6(1): 39–43.

Sadeghianfar P., Nazari M., Backes G., 2019. Exposure to Ultraviolet (UV-C) Radiation Increases Germination Rate of Maize (*Zea maize* L.) and Sugar Beet (*Beta vulgaris*) Seeds. *Plants (Basel, Switzerland)*, 8(2): 49. https://doi.org/10.3390/plants8020049

Sarghein S. H., Carapetian J., Khara J., 2011. The effects of UV radiation on some structural and ultrastructural parameters in pepper (*Capsicum longum* A. DC.). *Turkish journal of Biology*, 35(1): 69–77. https://doi.org/10.3906/biy-0903-11

Semenov A., Korotkova I., Sakhno T., Marenych M., Hanhur V., Liashenko V., Kaminsky V. F., 2020. Effect of UV-C radiation on basic indices of growth process of winter wheat (*Triticum aestivum* L.) seeds in pre-sowing treatment. *Acta Agriculturae Slovenica*, 116: 49–58. doi: 10.14720/aas.2020.116.1.1563

Stefanello R., Almeida R., Barreto M., Müller G. L., Henrique A., Rodrigues S., Dorneles D. S., 2023. UV-B and UV-C radiation on the germination of soybean seeds. *Revista Brasileira de Ciências Agrárias - Brazilian Journal of Agricultural Sciences*. https://doi.org/10.5039/agraria.v18i2a2964

Tahjib-Ul-Arif M., Hasan M. T., Rahman M. A., Nuruzzaman M., Rahman A. S., Hasanuzzaman M., Brestic M., 2023. Plant response to combined salinity and waterlogging stress: Current research progress and future prospects. *Plant Stress*, 7: 100137. https://doi.org/10.2139/ssrn.4663385

Thomas T. D., Dinakar C., Puthur J. T., 2020. Effect of UV-B priming on the abiotic stress tolerance of stress-sensitive rice seedlings: Priming imprints and cross-tolerance. *Plant Physiology and Biochemistry*, 147: 21–30. https://doi.org/10.1016/j.plaphy.2019.12.002

Urrutia J. D., Diaz J. L. B., Mingo F. L. T., 2017. Forecasting the Quarterly Production of Rice and Corn in the Philippines: A Time Series Analysis. *Journal of Physics: Conference Series*, 820 (1): 12007. https://doi.org/10.1088/1742-6596/820/1/012007

Widodo C. S., Herenda S., Didik R. S., 2018. The effect of NaCl concentration on the ionic NaCl solutions electrical impedance value using electrochemical impedance spectroscopy methods. *Proceedings of the AIP Conference*, 21(1). https://doi.org/10.1063/1.5062753

Zhang R., Yue Z., Chen X., 2023. Effects of waterlogging at different growth stages on the photosynthetic characteristics and grain yield of sorghum (*Sorghum bicolor* L.). *Sci Rep*, 13: 7212. https://doi.org/10.1038/s41598-023-32478-8