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IMPACT OF ULTRAVIOLET RADIATION ON GERMINATION AND GROWTH DYNAMICS OF SAFFRON (*CROCUS SATIVUS* L.) SEEDS

Nahid Akhtar Batool[*1], Muhammad Naeem[2], Muhammad Shafiq Khan[3], Sania Begum[4], Sahir Hameed Khattak[5], Maria Saeed[6], Sumaira Hafeez[7], Laiba Mahmood[8], Muhammad Aqeel Aslam[9], Mamoon Ahmad[10], Muhammad Laiq[11]

[*1]*Mohi-ud-din Islamic University, Nerian Sharif, Azad Jammu Kashmir*
[2]*School of Agriculture and Biology, Shanghai Jiao Tong University, Shanghai China*
[3]*Department of biotechnology Mohi-ud-Din Islamic University (MIU) Nerian Sharif*
[4,6]*National Institute for Genomics and Advanced Biotechnology, National Agriculture Research Center, Park Road, Islamabad, Pakistan*
[5,9,10]*Oilseeds Research Program, National Agricultural Research Center, Park Road, Islamabad, Pakistan*
[7]*Department of Plant Bleeding & Molecular Genetics, Faculty of Agriculture, University of Poonch, Rawalakot Azad Kashmir*
[8]*Wheat Research Institute, College of Life Sciences and Agri-forestry, Southwest University of Science and Technology, Mianyang, Sichuan 621010, P. R. China*
[11]*Department of Botany, university of Buner*

[*1]nahidbukhari83@gmail.com, [2]mnaeem@sjtu.edu.cn, [3]astpbiotech.shafiq@miu.edu.pk, [4]sania.idrees@parc.gov.pk,[5]sahir_999@hotmail.com, [6]mariasaeed784@gmail.com, [7]sumaira.hafeez9@gmail.com, [8]mahmoodlaiba892@gmail.com, [9]aqeel.aslam.wsu@gmail.com, [10]mamoonktk797@gmail.com, [11]mlaiqfalak@gmail.com

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Corresponding Author: *
Nahid Akhtar Batool

Abstract

Background: *Ultraviolet (UV) radiation can act as an abiotic elicitor influencing seed germination and early seedling development in economically important crops such as saffron (Crocus sativus L.).*

Objective: *To evaluate the effect of different durations of ultraviolet radiation on the germination behavior and early growth dynamics of saffron seeds.*

Methodology: *This laboratory-based experimental study was conducted over six months using saffron seeds obtained from a certified gene bank. A total of 30 seeds were used, divided into six groups (n = 5 per group): control (no UV exposure) and UV-treated groups exposed for 10, 20, 30, 40, and 50 minutes. Following UV treatment, seeds were germinated under controlled conditions, and germination percentage was recorded. Germinated seedlings were transferred to pots for assessment of morphological parameters (plant height, leaf number, leaf length and width, root traits) and biochemical attributes (chlorophyll and proline content) over a two-month period.*

Results: *Germination was observed in all groups, but timing and percentage varied with UV exposure duration. Seeds exposed to 20 and 30 minutes UV showed the highest and earliest germination (up to ~80–90%) within 48 hours, compared to delayed germination in the control group (~60–65% by day 6). Prolonged exposure (50 minutes) resulted in slower and reduced germination (~50–55%). Seedlings from the 20-minute UV group exhibited superior growth,*

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with the greatest plant height (17 cm), highest leaf number (8), enhanced root development, increased chlorophyll content, and maximum proline accumulation, while longer exposures showed inhibitory effects.

Conclusion: *Moderate UV exposure, particularly for 20 minutes, optimally enhances saffron seed germination and early seedling vigor, whereas prolonged exposure adversely affects growth.*

INTRODUCTION

Saffron is derived from the Arabic word "Zofran," meaning "yellow." Its scientific name is *Crocus sativus* L., and it belongs to the family *Iridaceae* (order *Liliales*, class Monocots) [1]. Saffron spice is obtained from the dried stigmas of *Crocus sativus*, and it is highly valued for its distinctive aroma and color [2]. Studies have identified over 150 volatile compounds in saffron extract, contributing to its unique sensory properties [3].

Globally, saffron cultivation remains concentrated in a handful of major producing regions, with Iran continuing to dominate (producing roughly 90% of the world's supply)**, followed by** Afghanistan, India (especially the Kashmir Valley), Spain, Greece, Italy, Morocco, and emerging areas in the United States and North Africa [4]**.**

Although saffron inherently requires relatively low water inputs due to its drought-adapted physiology, the crop is highly sensitive to environmental stresses during early development, particularly at the seed germination and seedling stages [5]. Climate change, soil degradation, and unpredictable weather patterns adversely affect germination rates and early seedling vigor, ultimately impacting yield [6]. Among these stresses, ultraviolet (UV) radiation represents a critical abiotic factor that can influence seed germination, seedling growth, and biochemical responses such as chlorophyll synthesis and proline accumulation [7].

Saffron cultivation faces additional challenges, including pests, diseases, and resource limitations, which can further compromise plant establishment [8]. Optimizing pre-sowing treatments to enhance seed germination and early growth has therefore become a research priority [9]. In this context, ultraviolet (UV) radiation has emerged as a potential elicitor, capable of stimulating metabolic activity, modulating stress-responsive biochemical pathways, and influencing morpho-physiological traits during germination and seedling development [10,11].

However, there is limited information on how saffron seeds respond to controlled UV exposure, particularly in relation to germination timing, growth dynamics, and early physiological responses. Understanding these effects is critical for developing novel low-cost agronomic interventions to improve saffron establishment and resilience under challenging environmental conditions.

Research Objective: To evaluate the effect of different durations of ultraviolet (UV) radiation on the germination behavior of saffron (*Crocus sativus* L.) seeds.

Methodology

Study Design

This experimental laboratory-based study was conducted to evaluate the effect of different durations of ultraviolet (UV) radiation on seed germination, growth dynamics, and biochemical responses of saffron (*Crocus sativus* L.) under controlled conditions.

Study Setting

The study was carried out using saffron seeds obtained from the Gene Bank, Plant Genetic Research Institute (PGRI). Soil samples were collected from an open field at the National Institute for Genomics and Advanced Biotechnology (NIGAB). All experimental procedures, including UV exposure, germination, growth assessment, and biochemical analysis, were performed under laboratory and controlled pot-culture conditions.

Study Duration

The total duration of the study was six (6) months, which included seed treatment, germination assessment, vegetative growth observation, and biochemical analysis.

Experimental Setup

To assess the effect of UV radiation, saffron seeds were selected from the Gene Bank at the Plant Genetic Research Institute (PGRI). Soil samples were collected from an open field at NIGAB, dried under sunlight for two days, and cleared of all visible vegetation. Seeds were pre-treated by transferring them to a refrigerator at 4°C for 6–8 hours. After chilling, seeds were placed in Petri dishes lined with Whatman No. 01 filter paper. Replicates were prepared, with each set consisting of five seeds. Seeds were exposed to UV radiation at different durations (10, 20, 30, 40, and 50 minutes), ensuring direct exposure of UV light to the seed surface. One replicate served as the control group without UV exposure.

Preparation of Soil

Soil was prepared using a mixture of 40% sand, 40% soil, and 20% peat moss. The soil mixture was autoclaved to eliminate contaminants and vegetation. Equal quantities of soil were transferred into plastic pots arranged into six groups and labeled as C (control), UV10, UV20, UV30, UV40, and UV50.

Germination of Seeds

Following UV radiation exposure, Petri dishes containing seeds were kept under laboratory conditions. Filter papers were moistened daily with 2 µL of distilled water to maintain humidity. Germination percentage was recorded daily. After six days, germinated seeds were transferred to pots and planted at a depth of 1 inch. The complete germination process required approximately six days.

Growth Parameters

To evaluate growth performance, morphological parameters including shoot length, root length, leaf length, leaf width, and plant height were measured at regular intervals throughout the study period.

Biochemical Observations

Chlorophyll Content Measurement

Chlorophyll content was measured using the method described by Arnon (1949). Fresh young leaves were weighed and immediately immersed in 10 ml of 80% ethanol in test tubes. Samples were heated in a water bath at 80°C for 10 minutes and then cooled to room temperature. Optical density was measured at 650 and 630 nm using 80% ethanol as a blank in a 1 cm quartz cuvette.

Proline Content Measurement

Proline content was determined following the method of Bates et al. (1973). Fresh leaf material (0.5 g) was homogenized in 3% aqueous sulphosalicylic acid and filtered through Whatman No. 2 filter paper. A reaction mixture consisting of 2 ml filtrate, 2 ml acidic ninhydrin, and 2 ml glacial acetic acid was heated at 100°C for 60 minutes. After cooling in an ice bath, 4 ml of toluene was added and mixed vigorously for 15–20 seconds. The organic phase was separated, and absorbance was measured at 520 nm. Proline concentration was calculated using a standard calibration curve and expressed on a fresh weight basis.

Ethical Approval

As this study involved plant material only and did not include human or animal subjects, formal ethical approval was not required. However, all experimental procedures were conducted in accordance with institutional laboratory safety guidelines and standard research practices.

Results

Effect of UV light on germination of seed

The effect of ultraviolet (UV) radiation on saffron seed germination was evaluated at different exposure durations (10, 20, 30, 40, and 50 minutes) along with an untreated control. Germination was observed in all treatment groups, though the timing and rate varied with exposure duration (Figure 1). Seeds exposed to

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UV radiation for 20 and 30 minutes exhibited earlier germination, with visible emergence occurring within 48 hours. In contrast, seeds treated for 50 minutes showed delayed germination, initiating after approximately 76 hours. UV exposure for 10 minutes resulted in germination within 3–5 days, while the control seeds required up to 6 days to germinate. Overall, UV exposure did not inhibit seed germination at early stages, indicating that short to moderate exposure durations did not exert adverse effects on germination behavior.

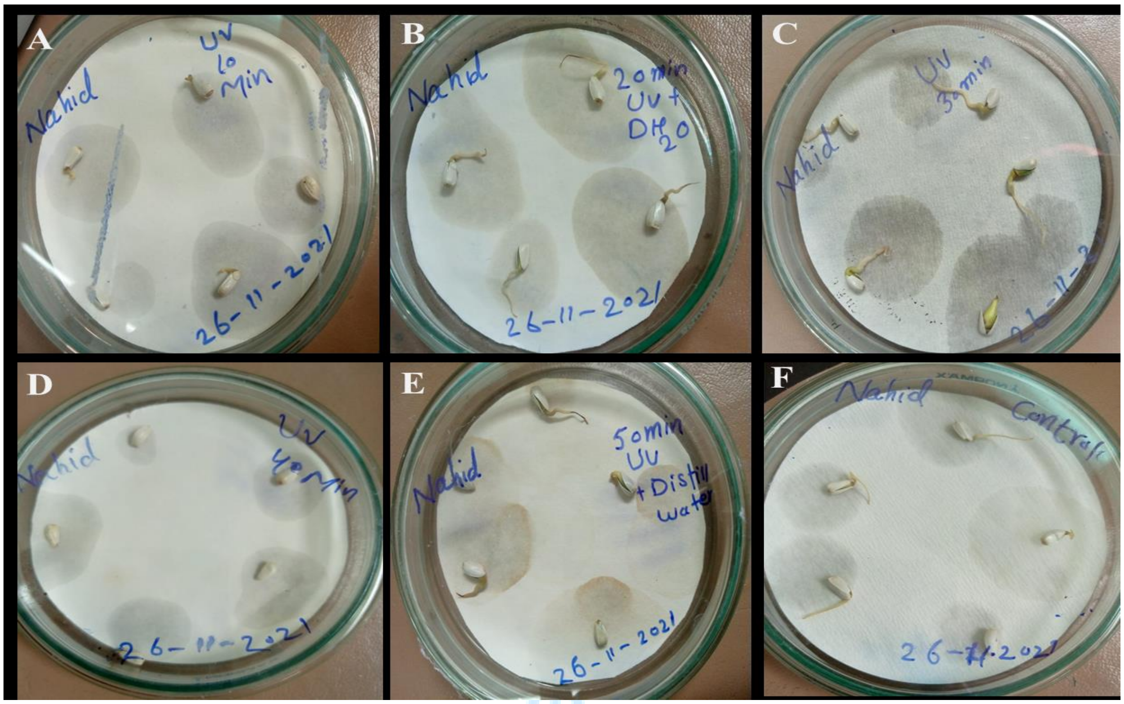

Figure 1. The UV effect on Saffron seeds germination at different times. (A) UV10, (B) UV 20, (C) UV 30, (D) UV40, (E) UV 50 and (F) control

PERCENTAGE OF GERMINATION OF SAFFRON

Percentage of germination was calculated by using formula: Total number of seed ÷ germinated seed×100. Germination percentage was calculated for all treatment groups. The highest and earliest germination was recorded in seeds exposed to UV radiation for 20 and 30 minutes, whereas prolonged exposure (50 minutes) resulted in slower germination. Control seeds showed comparatively delayed germination.

These observations indicate that moderate UV exposure accelerated the germination process, while longer exposure durations reduced germination speed.

Effect of UV Radiation on Seedling Growth Parameters

Morphological parameters including plant height, number of leaves, leaf length, and leaf width were measured at regular intervals. Clear variations were observed among UV-treated and control plants (Figure 2). During the initial growth phase, seedlings exposed to UV radiation for 20 minutes exhibited a more rapid increase in plant height, leaf number, and leaf dimensions compared to other treatments and the control group. Similar trends were recorded during subsequent observations over a two-month period. UV exposure for 30 minutes also showed enhanced growth, though to a lesser extent than the 20-minute treatment. In contrast, prolonged

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exposure durations (40 and 50 minutes) resulted in reduced growth performance. After 15 days of germination, plant height and growth rate were highest in the UV 20-minute treatment, followed by the UV 30-minute group. Growth was comparatively lower in the UV 50-minute treatment. Quantitative measurements of growth parameters are presented in Table 1.

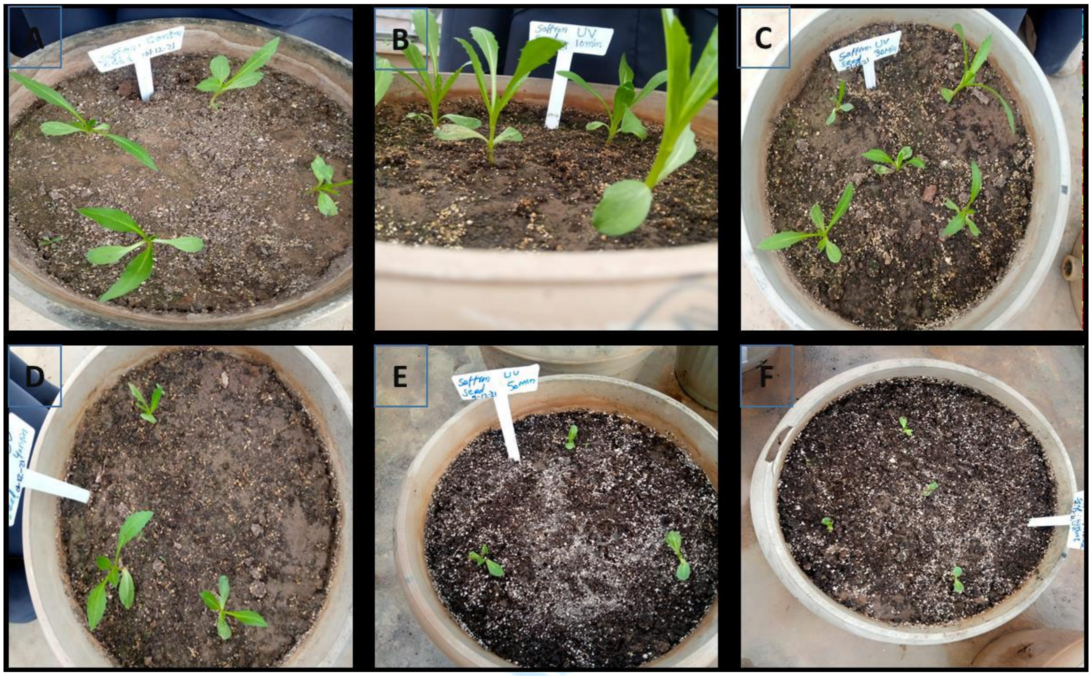

Figure 2. Plant height, no of leaves, leaves length and width measurements with different UV treatments (A) 10 min (B) 20 min (C) 30 min (D) 40 min (E) 50 min (F) control.

Table 1: Growth rate and plant height of saffron plant at different UV treatment

Sr. No	Leave length	Leave width	No of leaves	Plant height	Stalk diameter
1 control	0.1 cm	0.02 mm	3	1.8 cm	0.01 mm
2 UV 10 Min	0.3 cm	0.4 mm	2	2.5 cm	0.02 mm
3 UV 20 Min	0.6 cm	0.8mm	5	4 cm	0.3 mm
4 UV 30 Min	0.4 cm	0.5 mm	3	2.5 cm	0.1mm
5 UV 40 Min	0.4 cm	0.3 mm	2	2 cm	0.05mm
6 UV 50 Min	0.3 cm	0.2 mm	2	1.5 cm	0.02 mm

Growth Performance After One Month

Growth measurements were repeated after one month to assess sustained effects of UV radiation. Significant differences were observed among treatments (Figure 3). Plants treated with UV radiation for 20 minutes continued to show superior growth, with greater plant height, increased leaf number, and larger leaf dimensions compared to all other groups (Table 2). The UV 10- and 30-minute treatments showed moderate growth, while the UV 40- and 50-minute treatments displayed comparatively reduced development.

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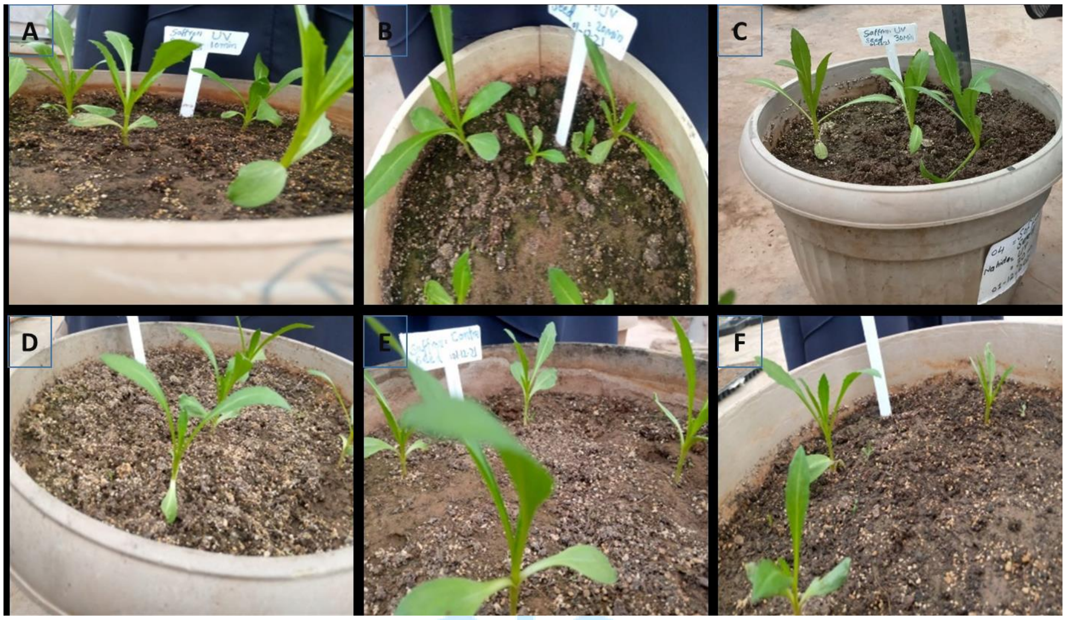

Figure 3. Plant height no of leaves, leaves length and width measurements with different UV treatments (A) 10 min (B) 20 min (C) 30 min (D) 40 min (E) 50 min (F) control.

Table 2: Observations were repeated after 1 month of growth

Sr. No.	Leave length	Leave width	No of leaves	Plant height	Stalk diameter
1 control	3 cm	1.2 mm	4	7.8 cm	1.06 mm
2 UV 10 Min	2 cm	1.4 mm	6	9.5 cm	2.02 mm
3 UV 20 Min	5 cm	2.8 mm	8	12cm	2.8 mm
4 UV 30 Min	2 cm	1.5 mm	5	10 cm	2.05 mm
5 UV 40 Min	1.5 cm	1.3 mm	4	6 cm	1.05mm
6 UV 50 Min	1 cm	1.2 mm	4	5 cm	1.03 mm

Morphological Observations After Two Months

After two months of growth, visible differences in overall plant vigor and morphology were evident among treatments (Figure 4). Plants subjected to 20 minutes of UV exposure maintained healthier appearance, stronger shoots, and more developed foliage. Control plants and those exposed to longer UV durations showed comparatively reduced growth and vigor.

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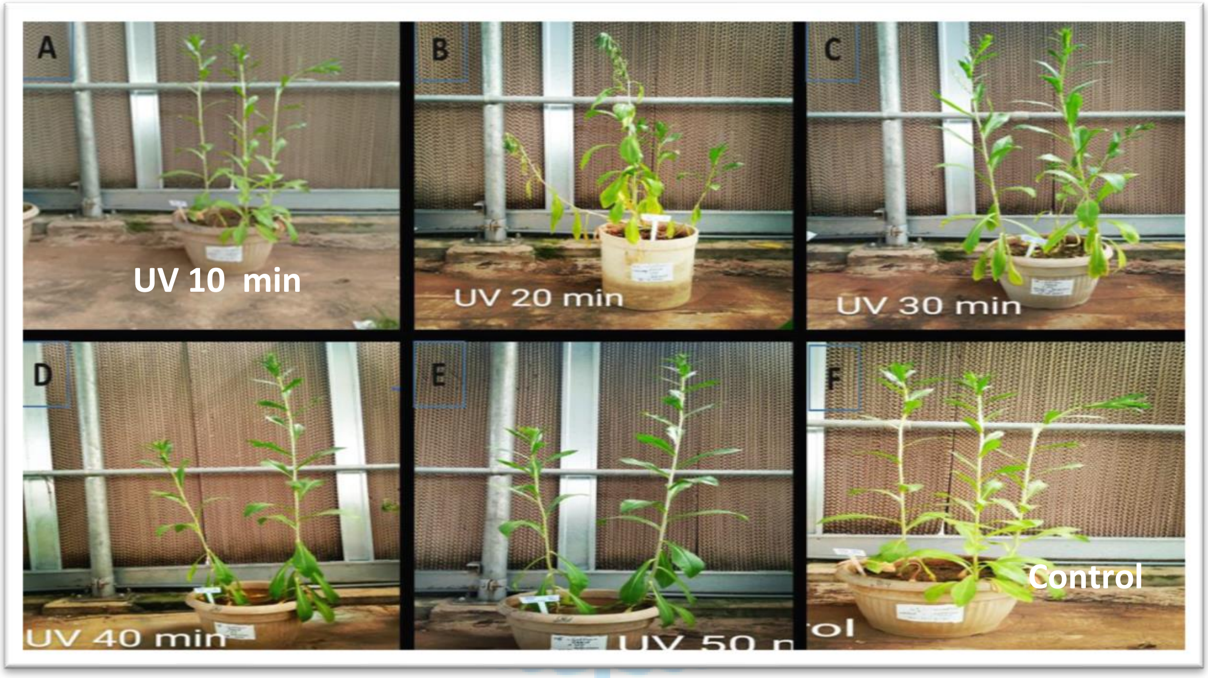

Figure 4 physiological appearances after two months of germination at different UV treatments (A) 10 min (B) 20 min (C) 30 min (D) 40 min (E) 50 min and (F) Control

Table 3 summarizes the morphological parameters of saffron seedlings measured over a two-month period, with observations recorded after 15 weeks. The data show that UV treatments of 20 and 30 minutes notably enhanced growth compared to the control, with the 20-minute exposure producing the tallest plants (17 cm), the highest number of leaves (8), and the largest leaf dimensions (8 cm × 4 mm). The 30-minute treatment also improved growth but to a lesser extent. Short UV exposure (10 minutes) resulted in moderate growth, while prolonged exposure (40–50 minutes) had inhibitory effects, with reduced plant height, fewer leaves, and smaller leaf size. These results indicate that moderate UV exposure optimizes early saffron seedling development, whereas excessive UV can hinder growth.

Table 3. Observations for the Morphological parameters

Sr. No.	Leave length	Leave width	No of leaves	Plant height	Stalk diameter
1 control	3 cm	2.2 mm	4	9.8 cm	1.06 mm
2 UV 10 Min	4 cm	2.8 mm	6	11.5 cm	2.02 mm
3 UV 20 Min	8 cm	4 mm	8	17 cm	3.8 mm
4 UV 30 Min	5 cm	2.6 mm	5	14 cm	2.09 mm
5 UV 40 Min	2.5 cm	2.3 mm	4	8cm	1.05mm
6 UV 50 Min	2 cm	1.8 mm	4	6 cm	1.04 mm

Root growth parameters, including root length, basal root count, and adventitious root formation, were analyzed using DIRT software (figure 5). UV-treated plants exhibited enhanced root development compared to the control group. The highest basal and adventitious root counts were recorded in plants exposed to UV radiation for 20 minutes, followed by the 30-

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minute treatment. Root area percentage and stem diameter were also higher in these groups. Prolonged UV exposure (40 and 50 minutes) resulted in reduced root development parameters (Table 4).

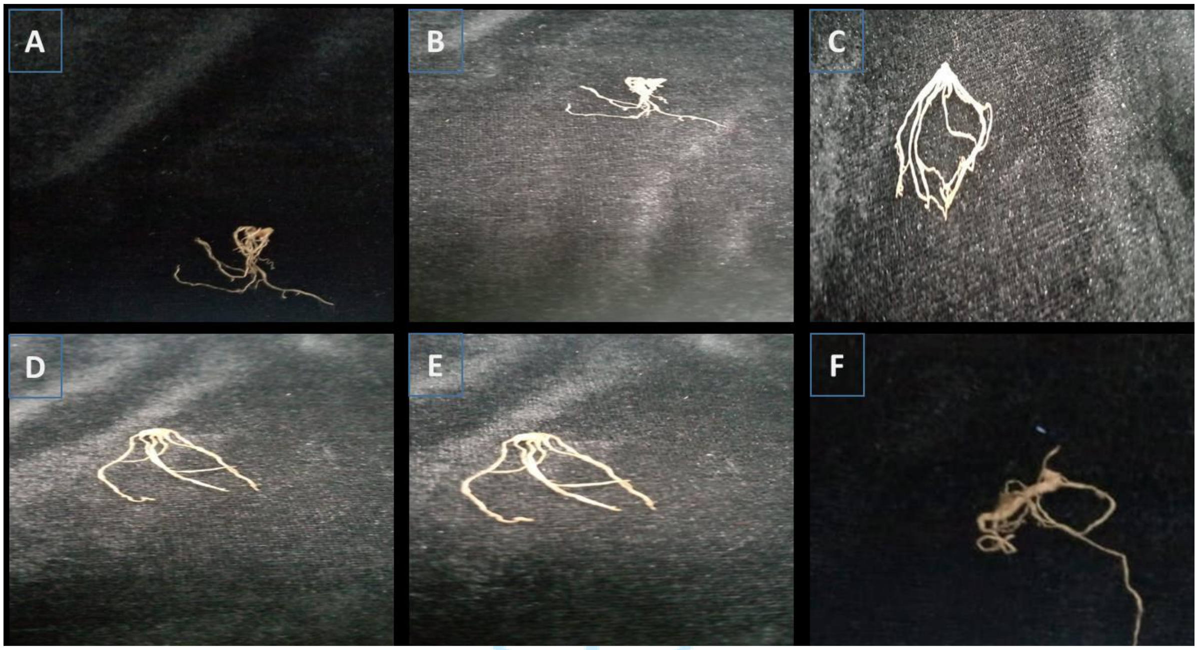

Figure 5: Effect of Different Durations of UV Radiation on Root Morphology of Saffron Seedlings After One Month

Table 4: Basal count after one month of germination at different UV treatments (A) 10 min (B) 20 min (C) 30 min (D) 40 min (E) 50 min and (F) Control.

Treatment	SKL Node	DIA STEM	Area %	Basal Count	ADVT-Count
1 control	3214	12.8082	13.6071	01 cm	2 cm
2 UV 10 Min	4967	12.0666	17.9956	03cm	3 cm
3 UV 20 Min	5420	14.1322	78.6071	05 cm	5 cm
4 UV 30 Min	2183	10.8993	26.1219	04 cm	4 cm
5 UV 40 Min	4106	5.06088	9.0345	0.1cm	2 cm
6 UV 50 Min	5161	8.3091	7.489	0.05cm	1 cm

Note: SKL (skeletal root), DIA (diameter), ADVT (Adventitious roots)

Chlorophyll content varied significantly among treatments (Figure 6). UV-treated plants showed higher chlorophyll levels compared to the control group. The highest chlorophyll content was recorded in plants exposed to UV radiation for 20 minutes, followed by 10- and 30-minute treatments. A gradual decline in chlorophyll content was observed with increasing UV exposure duration beyond 30 minutes (Table 5).

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Figure 6: Measuring of chlorophyll content in young leaves of UV treated plants

Table 5: Chlorophyll contents of UV treated plants

Treatment	Wave length 645 (645)	Wave length 645 (630)
1 control	4.785	2.013
2 UV 10 Min	5.986	2.135
3 UV 20 Min	6.362	3.155
4 UV 30 Min	5.997	2.053
5 UV 40 Min	5.964	1.086
6 UV 50 Min	5.745	1.18

Proline content analysis revealed noticeable variation across treatments (Table 6). The highest proline concentration was observed in plants exposed to UV radiation for 20 minutes, followed by the 10- and 30-minute treatments. Lower proline levels were recorded in plants treated for 40 and 50 minutes, as well as in the control group. These findings indicate that moderate UV exposure stimulated proline accumulation, while prolonged exposure reduced this response.

Table 6: Proline Content in Saffron Seedlings under Different Durations of UV Radiation

Treatment	**Values**
1 control	0.92
2 UV 10 Min	1.64
3 UV 20 Min	2.607
4 UV 30 Min	1.402
5 UV 40 Min	0.669
6 UV 50 Min	0.975

Discussion

Our results show that UV treatments of 30 and 20 minutes led to germination after 48 hours, while 50 minutes took 76 hours. UV 10 minutes took 3-5 days, and the control group germinated in 6 days. Studies suggest that UV radiation can stimulate seed germination, though results vary [12]. High UV doses negatively impact germination and growth rates in red beans, while sunflower seeds showed improved germination with UVC exposure [13]. In this study, UV radiation significantly impacted seed surface, aiding in seed breakdown and enhancing growth. Morphological traits like plant height, leaf number, length, and width were measured in centimeters. Our results show that UV exposure

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increased leaf length, width, and the number of leaves, with notable changes at specific times. Significant differences were observed between UV-treated and non-treated plants, with UV treatments of 20 minutes showing the most rapid increase in leaf number, size, and plant height compared to other groups. These results were consistent across all observations over two months. Previous studies report that UV radiation positively affects wheat somatic cells, aiding germination [14], and enhances shoot weight, root length, and leaf growth in groundnut seedlings [15].

After 15 days of germination, UV treatments of 20 and 30 minutes showed increased growth rates compared to the control (F), with plant height significantly higher in the 20-minute treatment compared to UV 10 minutes. UV 20 minutes had a positive effect on growth and height, outperforming the control and UV 40 (D). However, growth and height were lower in the UV 50-minute treatment (E). After one month, the experiment was repeated, and plant heights across all samples showed significant variations. Variations in wheat somatic cells showed positive effects from UV radiation, particularly aiding germination [14]. Groundnut seedlings exhibited increased shoot weight, root length, leaf area, and nodule number under UV exposure. Similar results were seen in Bengal gram (*Cicer arietinum*) when exposed to UVC for up to 17 minutes, positively impacting seed performance. In the current study on saffron, plant height, leaf number, and leaf dimensions were recorded over two months, with percentages documented after 15 weeks. UV light was found to enhance root growth by promoting mitotic division, resulting in longer roots compared to the control group. Basal and adventitious root counts were measured using Dirt software. Previous studies have noted that UVC exposure improves sprouting and biomass production [16]. In this study, UV radiation up to 50 minutes had a positive effect on saffron seed germination and groundnut productivity. Results showed increased basal stem, adventitious roots, and root area as UV exposure increased.

Chlorophyll content was highest (5.986) in the sample treated with UV for 10 minutes. UV-treated plants showed higher chlorophyll levels than the control, with shorter UV exposures increasing chlorophyll, while longer exposures reduced it. Proline content also increased significantly in UV-treated samples, with UV10, UV20, and UV30 treatments showing the most notable rise. UV exposure helps protect plants from oxidative damage, aligning with previous findings that UV radiation boosts proline levels, enhancing plant tolerance to stress [17,18].

Strengths and Limitations

This study has several strengths, including a controlled experimental design with clearly defined UV exposure durations, use of a control group, and comprehensive assessment of germination, morphological, root architectural, and biochemical parameters, providing an integrated view of saffron seed and seedling responses to UV radiation. Repeated observations over multiple growth stages and the use of image-based root analysis (DIRT software) further strengthen data reliability. However, limitations include a relatively small sample size per treatment, absence of statistical significance testing, lack of differentiation between specific UV wavelengths (UVA, UVB, UVC), and confinement to laboratory and pot conditions, which may not fully reflect field environments. Additionally, molecular-level responses were not assessed, restricting mechanistic interpretation of UV-induced effects.

Conclusion

UV radiation has significant effects on saffron (*Crocus sativus* L.) seeds, with observations recorded at various physiological and morphological stages. UV light positively influences seed germination, growth, productivity, and quality. UV-B radiation, in particular, enhances the rate of photosynthesis and water use efficiency and shows a positive effect on root length at medium wavelengths. At limited exposure, it also significantly influences the production of secondary metabolites. Additionally, UV radiation provides protection against herbivores that pose a threat to seeds during germination and growth stages. UV light confers resistance to plants that are otherwise unable to thrive in harsh environmental conditions. Another aspect of this study is the relationship between UV radiation and other environmental factors, which could lead to innovative agricultural approaches aimed at improving both the quality and quantity of products, particularly through the use of specialized greenhouse facilities. At low UV dosages, saffron plants exhibit increased resistance compared to control plants. However, at higher doses, undesirable effects such as leaf yellowing and stalk shrinkage were observed. Given the high economic value of saffron and the cultivation challenges it faces, treating plants with low doses of UV radiation presents a promising strategy to enhance saffron production globally.

Recommendations

UV radiation has posed a significant threat to living organisms for an extended period, as it can induce mutations and various micro- and macro-level changes. Plants, in particular, are consistently exposed to UV radiation, which may lead to developmental issues, reduced crop yield, and impaired growth. Therefore, it is essential to analyze the effects of UV radiation across different wavelengths and exposure durations. In our analysis, we observed physiological and biochemical changes following UV treatments; however, no significant molecular changes were detected. This study highlights the necessity for molecular-level investigations to complement physiological and biochemical assessments. Future research should employ various techniques, such as gene expression analysis, investigation of expression pathways, examination of structural motifs in genes, and three-dimensional protein analysis, to further explore the effects of UV radiation on plants, including saffron (*Crocus sativus* L.).

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