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ADAPTIVE RESPONSES OF CHICKPEA CULTIVARS TO UV-B RADIATION: IMPLICATIONS FOR GENETIC DIVERSITY AND CROP RESILIENCE

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ABSTRACT

Increasing awareness has emerged regarding the impact of ultraviolet B (UV-B) radiation (280–315 nm) on plant development and overall yield, particularly in the context of global climate change. Chickpea (*Cicer arietinum* L.), a crop widely valued worldwide for its nutritional and economic importance, exhibits cultivar-specific responses to UV-B exposure, highlighting the critical role of genetic diversity in stress adaptation. This review synthesizes recent studies on the responses and adaptive mechanisms of chickpea cultivars to UV-B radiation. It focuses on the genetic, physiological, biochemical, and morphological mechanisms underlying stress tolerance. UV-B-induced damage to DNA and associated molecular changes can alter gene expression and modulate stress-response traits. Plant growth and productivity are ultimately influenced by the physiological effects of UV-B radiation on processes such as transpiration, photosynthesis, and nutrient uptake. Elevated UV-B levels generally impair normal plant functioning, reducing water-use efficiency, stomatal development, and metabolic activity, which in turn limit biomass accumulation and yield. However, certain genotypes exhibit enhanced tolerance to UV-B stress. These genotypes activate effective photo protective mechanisms and adjust physiological processes to maintain essential functions and sustain growth. In addition to physiological and biochemical responses, chickpea plants also undergo significant morphological adaptations that mitigate UV-B damage. These include the development of a thicker cuticle (a waxy outer layer), changes in leaf morphology, and modifications in root and shoot architecture. Such adaptations improve the plant's capacity for water and nutrient uptake as well as light utilization, thereby enhancing stress tolerance.

Keyword: chickpea; mutation; UV-B rays; stress tolerance; genetic variability.

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1. INTRODUCTION

Chickpea (*Cicer arietinum* L.) is an important grain legume crop predominantly cultivated in arid and semi-arid regions. It belongs to the Fabaceae family and is widely recognized as a valuable source of plant-based protein and essential nutrients for human consumption. Chickpea is typically grown during the Rabi (winter) season and is cultivated commercially in countries such as Ethiopia, Australia, Iran, Pakistan, India, and Turkey. India is the largest producer, accounting for over 70% of global chickpea production [1].

Chickpea is broadly classified into two main types: Desi and Kabuli. Desi chickpeas are smaller, darker, and have a rough seed coat, whereas Kabuli chickpeas are larger, lighter in color, and possess a smoother surface. Chickpea cultivation contributes significantly to soil fertility due to its ability to fix atmospheric nitrogen. It is generally accepted that the small-seeded Desi types ("microsperma") gave rise to the large-seeded Kabuli types ("macrosperma") [2]. Notably, Kabuli chickpeas exhibit lower genetic diversity compared to Desi types, indicating reduced variability within this group.

India dominates global chickpea production, with major cultivation concentrated in states such as Madhya Pradesh, Maharashtra, Rajasthan, Uttar Pradesh, Andhra Pradesh, Karnataka, and Telangana [3]. In Uttar Pradesh, chickpea is cultivated across most districts, with Bundelkhand, Purvanchal, and the south-western regions contributing the largest share. During the 2024–2025 growing season, chickpea was cultivated on approximately 0.55 million hectares in Uttar Pradesh, with a total production of about 0.65 million tons. The average yield in the state is approximately 1.2 tons per hectare [3, 4].

Ultraviolet-B (UV-B) radiation is an important environmental factor influencing plant growth and productivity. In chickpea, short-term exposure to UV-B radiation (1–2 hours per day) may stimulate certain developmental processes, such as increased flower and pod formation. However, prolonged exposure (approximately 3 hours per day or more) adversely affects plant growth, reduces reproductive capacity, and limits yield. UV-B radiation can decrease chlorophyll content by 15–25%, thereby impairing photosynthesis and reducing the plant's ability to capture and utilize energy for growth.

At the cellular level, UV-B exposure induces the production of reactive oxygen species (ROS), which can cause oxidative damage if not effectively neutralized by the plant's antioxidant defense system. Consequently, prolonged UV-B stress negatively affects not only fertilization processes but also overall plant health, development, and productivity [5].

The aim of this review is to analyze the adaptive responses of chickpea cultivars to UV-B radiation, with particular emphasis on physiological, biochemical, and genetic mechanisms underlying stress tolerance, and to evaluate their significance for improving genetic diversity and crop resilience.

2. MATERIALS AND METHODS

2.1 Source Material

This review is based on previously published scientific literature focusing on the effects of ultraviolet-B (UV-B) radiation on chickpea (*Cicer arietinum* L.) and other higher plants. Particular attention was given to studies addressing physiological, biochemical, molecular, and morphological responses to UV-B stress, as well as research on genetic variability and mutation breeding in chickpea. The analysis includes both experimental studies and review articles that investigate plant stress tolerance mechanisms, UV-B-induced damage, and adaptive responses at different levels of biological organization.

2.2 Data Sources and Search Strategy

A comprehensive literature search was conducted using major scientific databases, including Web of Science Core Collection, PubMed, Scopus, and Google Scholar. A total of more than 60 relevant publications were selected, including original research articles, review papers, and book chapters published in peer-reviewed international journals. The selected literature covers the period from 1990 to 2025, ensuring inclusion of both foundational and recent studies on UV-B radiation effects and chickpea biology.

The selection criteria focused on studies related to:

- Effects of UV-B radiation on plant growth, development, and productivity;
- Physiological and biochemical responses to UV-B stress (e.g., photosynthesis, ROS production, antioxidant systems);
- Molecular mechanisms, including DNA damage, repair pathways, and gene expression;
- Genetic diversity and cultivar-specific responses in chickpea;
- Mutation breeding and stress tolerance improvement strategies in legumes.

2.3 Research Tools and Keywords

The literature search was performed using a combination of controlled vocabulary and free-text keywords. The primary search terms included: “chickpea”, “*Cicer arietinum*”, “UV-B radiation”, “abiotic stress”, “stress tolerance”, “genetic diversity”, “mutation”, “reactive oxygen species (ROS)”, “antioxidant defense”, “photosynthesis”, and “plant adaptation”. Search filters were applied to include only peer-reviewed publications in English. Priority was given to studies with strong experimental design, clear methodological approaches, and relevance to plant stress physiology, molecular biology, and crop improvement.

2.4 Study Selection and Data Extraction

The study selection process followed a structured approach adapted from systematic review methodology. Initially, all identified records were screened based on titles and abstracts to assess their relevance to the topic. Duplicate records were removed. Full-text articles were then evaluated according to predefined inclusion and exclusion criteria. Inclusion criteria: studies focusing on the effects of UV-B radiation on plants, particularly chickpea (*Cicer arietinum* L.); research addressing physiological, biochemical, molecular, or morphological responses to UV-B stress; articles investigating genetic variability, mutation breeding, or stress tolerance mechanisms; peer-reviewed publications in English. Exclusion criteria: studies not related to UV-B radiation or plant stress responses; articles lacking sufficient methodological detail or scientific rigor; non-peer-reviewed sources, abstracts without full text, and duplicate publications.

2.5 Limitations of the Review

This review has several limitations. First, the analysis is restricted to publications available in English, which may exclude relevant studies published in other languages. Second, variability in experimental designs, including differences in UV-B intensity, exposure duration, and plant growth conditions, may limit direct comparability between studies. Additionally, while chickpea-specific studies were prioritized, in some cases findings from other plant species were considered to provide broader insights into UV-B response mechanisms. Finally, the review is based on qualitative synthesis rather than quantitative meta-analysis, which may limit the ability to statistically generalize the results.

3. MUTAGENESIS AND ITS ROLE IN CHICKPEA IMPROVEMENT

Mutagens are biological, chemical, or physical (radiation) agents that can induce irreversible and heritable changes in DNA [6]. As mutagens are responsible for inducing genetic variation in plants, the selection of an appropriate mutagen is crucial in mutation breeding, since different mutagens exhibit distinct mutagenic properties [7]. Mutagens are broadly classified into two main categories: physical and chemical. Physical mutagens: X-rays, gamma rays, ultraviolet (UV) radiation, β-particles, neutrons, and accelerated particles. Chemical mutagens: base analogues, antibiotics, alkylating agents, acridines, azides, hydroxylamine, and nitrous acid.

3.1 Physical mutagens. Physical mutagens are often considered advantageous over chemical mutagens because they do not generate hazardous residues and do not require post-treatment disposal [8]. The earliest documented use of physical mutagens dates back to the 1920s, when radium was shown to induce mutagenic effects in insects [9]. Following the discovery of the genetic effects of ionizing radiation by Muller and Stadler [10], physical mutagens have been widely used and are responsible for generating more than 70% of induced mutants reported to date [11]. Muller first demonstrated X-ray-induced mutations in fruit flies in 1927, while Stadler reported the genetic effects of X-rays on barley and maize in 1928 [12]. These discoveries significantly contributed to the widespread application of physical mutagens in mutation breeding.

3.2 Chemical mutagens. During the early decades of the 20th century, numerous studies explored the induction of mutations using chemical agents. In 1939, Thomson and Steinberger reported the first convincing evidence of chemical mutagenesis using nitrous acid in *Aspergillus*. Later, Auerbach and Robson [13] demonstrated the strong mutagenic properties of mustard gas. Initially, there was uncertainty regarding whether chemical mutagens could induce mutations as effectively as physical mutagens; however, subsequent studies confirmed that chemical mutagens can be equally efficient in inducing genetic changes. Since then, a wide range of chemical mutagens has been identified, including nitrous compounds, base analogues, asides, acridine dyes, and alkylating agents [14, 15]. However, chemical mutagens may leave hazardous residues and pose potential health risks, including carcinogenic effects. In contrast, physical mutagens are generally considered safer due to the absence of such residual effects.

4. EFFECTS OF MUTATION IN CHICKPEA PLANTS

Ultraviolet-B (UV-B) radiation reaching the Earth's surface has increased as a result of ozone layer depletion [16]. Elevated levels of UV-B radiation significantly affect plant growth and metabolism. Consequently, UV-B acts as an important abiotic stress factor, inhibiting plant growth, damaging photosynthetic pigments, reducing carbon assimilation, and altering biomass allocation, which ultimately leads to decreased biomass accumulation and productivity [17].

Plant responses to UV-B radiation vary considerably among species and genotypes. Some plants exhibit tolerance, while others are more sensitive and unable to effectively cope with this stress. To mitigate the adverse effects of UV-B radiation, plants have evolved a range of defense mechanisms, including the development of thicker leaves, increased accumulation of flavonoids, enhancement of antioxidant systems, and activation of reactive oxygen species (ROS)-scavenging pathways.

At the cellular and molecular levels, UV-B radiation can induce DNA damage, photodamage, membrane alterations, protein degradation, and disruption of hormone balance. These effects are mediated through complex signaling pathways, including phytochrome-mediated signal transduction [18] and UV-B-specific photoreceptors, which regulate gene expression and stress-response mechanisms [17, 19], table 1.

5. UV-B-INDUCED STRUCTURAL AND PHYSIOLOGICAL CHANGES

5.1 Structural Changes

Plant morphology is considered a reliable indicator of UV-B damage. Additional parameters, including chlorophyll, carotenoids, phenolic compounds, and lipid peroxidation, have also been used as markers of UV-B sensitivity and tolerance. Although UV-B radiation constitutes a very small portion of the solar spectrum, it induces a wide range of morphological effects in plants.

These changes include variations in the root-to-shoot ratio, increased leaf thickness, altered leaf coloration, and leaf serration [32]. UV-B-induced loss of photosynthetic pigments reduces leaf area; however, affected plants may produce more leaves to compensate and maintain photosynthetic activity. This often results in increased branching in dicots. Flowering and fruiting can be reduced, as repair and defense mechanisms consume significant energy. Additionally, plants employ a protective strategy of thickening leaves to increase the optical path of UV radiation, thereby minimizing damage.

Table 1– Characteristics of UV radiation types and their impact on plant growth, stress responses, and adaptation mechanisms.

UV -Type	Wavelength	Effect on Plants	Reference
UV-A	315–400 nm	Generally beneficial in small amounts; influences photo morphogenesis, leaf orientation, pigmentation	[20-26]
UV-B	280–315 nm	Stressful but adaptive can reduce growth at high levels, but also triggers protective compounds (flavonoids, antioxidants)	[20-22, 24, 25, 27, 28]
UV-C	100–280 nm	Highly damaging; causes DNA damage and cell death; normally blocked by ozone (used only artificially for sterilization)	[20, 25, 27-31]

5.2 Physiological Changes

Photosynthesis, the process by which carbon dioxide (CO_2) and water are converted into carbohydrates in the presence of sunlight, involves the photosystems PS-I and PS-II. UV-B adversely affects multiple components of photosynthesis, including the molecular structure of chloroplasts and light-harvesting complexes, Rubisco activity, oxygen evolution and CO_2 fixation, and the content of starch and chlorophyll. The extent of photosynthetic impairment depends on plant species, cultivar, growth conditions, UV-B dosage, and the ratio of photosynthetically active radiation (PAR) to UV-B radiation. Elevated UV-B also induces ultrastructural changes in leaves, which alter light attenuation and UV-B absorption, further affecting photosynthesis. Leaf surfaces reflect a portion of incident UV-B light: pubescent or waxy surfaces reflect approximately 3–6% [33, 34], while other leaf types can reflect 10–40% of UV-B [35]. Reduced surface reflectance allows greater transmission of UV-B into leaf tissues. Morphological responses to UV-B vary among plant species, but increased leaf thickness is a common adaptation [36, 37], the overall effect of UV-B radiation on chickpea growth and physiology is summarized in Figure 1.

5.3 Biochemical and metabolism Modifications

The detrimental effects of UV-B on various physiological and biochemical traits of commercially important plants are well recognized [38–40]. Chromophores associated with the photosynthetic machinery absorb UV-B radiation after it passes through the leaves. More than 90% of incident UV-B is absorbed by leaf tissues, with very little transmission, and leaf surface reflectance at this wavelength is typically less

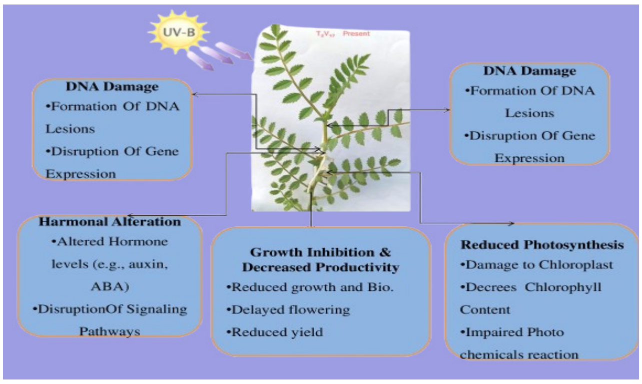

Figure 1 – Effect of Uv-B radiation on chickpea growth and physiology.

than 10% [35, 41, 42]. In addition, cellular components such as nucleic acids, proteins, lipids, and quinones can directly absorb UV-B radiation [43]. The overall biochemical changes and their role in plant metabolic modifications under UV-B stress are summarized in Figure 2.

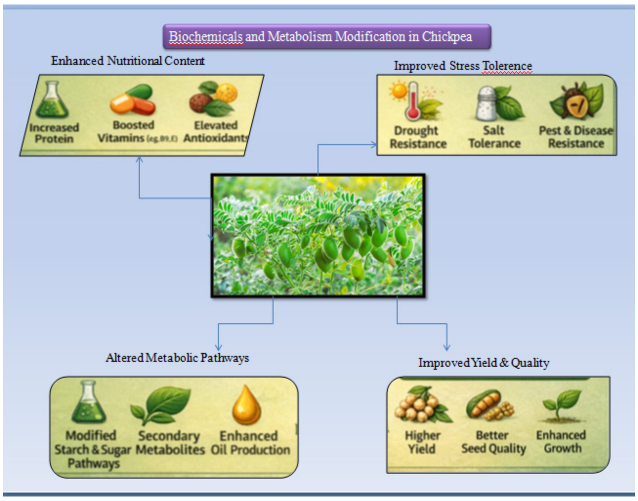

Figure 2 – Summary of UV-B-induced biochemical changes and their role in plant metabolic regulation.

5.4 Antioxidant Defense Systems

When plants are exposed to stress, they produce ROS, which can damage cellular components. Antioxidants protect cells by neutralizing these free radicals, and a strong antioxidant system is crucial for preventing membrane damage and oxidative stress [44]. The effectiveness of antioxidant defense varies depending on the type and intensity of stress, as well as among plant species and genotypes [45]. Antioxidant defense mechanisms are essential under stress conditions because they help delay programmed cell death. When plants lack sufficient antioxidant enzymes to neutralize excessive ROS, cellular organelles cannot function effectively, resulting in lipid peroxidation, protein oxidation, DNA and nucleic acid degradation, and inhibition of several enzymatic activities [46]. The overall role of antioxidant defense systems in plant development under stress conditions is summarized in Figure 3.

6. DNA REPAIR AND PHOTOPROTECTIVE MECHANISMS IN CHICKPEA UNDER UV-B STRESS

6.1 Light Avoidance and Photoprotection

Plants withstand UV-B radiation through a combination of exposure avoidance, defensive responses, and DNA repair mechanisms, reducing exposure to excessive light is an effective strategy to manage light stress, for example, chloroplasts can reposition within plant cells to limit absorption of intense light and protect photosystem II (PSII) from damage [47].

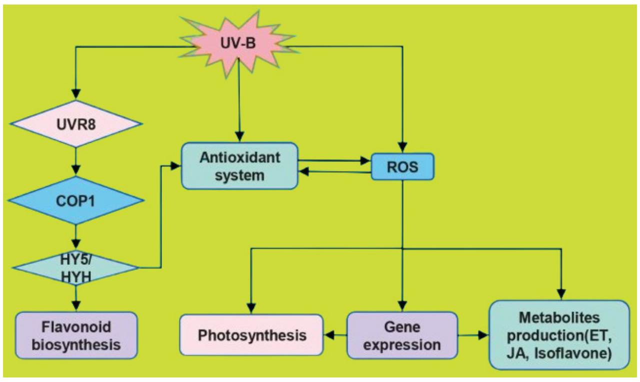

Figure 3 – Overview of antioxidant defense systems and their function in protecting plants from oxidative damage.

6.2 Genome Integrity and DNA Replication

Precise transmission of genetic information from parent to daughter cells is essential for survival, requiring accurate DNA replication and chromosome segregation while minimizing environmentally induced DNA damage and inherited mutations [48].

6.3 DNA Repair Pathways

The base excision repair (BER) pathway protects cells from DNA damage caused by reactive oxygen species, metabolic by-products, alkylating agents, and ionizing radiation Photoreactivation is an ancient DNA repair mechanism involving the enzyme photolyase which repairs lesions such as 6-4 photoproducts (6-4PPs) and cyclobutane pyrimidine dimers (CPDs) using light energy [49]. UVR8 is a plant-specific UV-B photoreceptor evolved from green algae that regulates growth and stress responses under UV-B exposure [50-52].

6.4 Gene Expression and Stress-Responsive Mechanisms

Plants under drought and UV-B stress modify gene expression by upregulating stress-responsive genes, accumulating stress-tolerance proteins and osmolytes, and altering cellular and molecular pathways including stomatal closure, reduced growth and photosynthesis, and increased respiration [53, 54], key cis-acting elements such as ABRE and DRE/CRT regulate stress-inducible genes like RD29A in response to cold, salt, and drought stress

6.5 Primer Design for Stress-Responsive Genes in Chickpea

Primers for chickpea genes were designed using heterologous sequences from Medicago for ASR, SuSy, and SPS genes or consensus/degenerate primers for the ERECTA gene, and sequence-specific primers from chickpea ESTs under abiotic stress were used to isolate gene homologs [55]. Table 2 summarizes chickpea mutation research including types of induced and chemical mutants and their characteristics.

Table 2 summarizes chickpea mutation research, including types of induced and chemical mutants and their characteristics. These mutants provide valuable genetic resources for understanding stress tolerance mechanisms, as many exhibit

Table 2 – Types and characteristics of induced and chemical mutants in chickpea.

Serial Number	Chickpea Genotype/ mutant	Mutagen Used	Results	Reference
1	CO-4	Gamma rays + EMS	High frequency of chlorophyll mutants (Viridis dominant)	[56]
2	Vishal	Gamma rays, EMS, SA	Morphological variability and chlorophyll mutations	[57]
3	GNG-1958	Gamma rays + EMS	Determination of effective mutagen doses, chlorophyll mutation spectrum	[58]
4	BG-212, JG-11	Gamma rays + EMS	Reduction in germination and plant height in M_1; variation in growth habit and yield components.	[59]
5	Pant Chickpea Genotypes	Gamma rays, EMS	Enhanced genetic variability in M_2 generation	[60]
6	Pusa-547, RSG (Kiran)	Induced mutation	High yield and bold seed size, early maturity and high podnumber	[61]
7	Kabuli genotype Ghab-4	Gamma rays	Increased variability for flowering and yield traits	[62]
8	Desi mutant line D1M-2HT-2, D1M1HT-2, D1M1HT-3, Kabuli mutant KM3HT-2, KM-4HT-1, KM1HT-4	EMS + Gamma rays	Higher seed yield and pods/plant; improved agronomic traits, enhanced seed yield; improved yield performance, moderate yield improvement; variation in seed traits	[63]
9	Desi chickpea mutants, Glyphosate-tolerant mutants	EMS + Gamma rays	Development of herbicide tolerant lines; high tolerance to glyphosate	[63]
10	Glyphosate-tolerant mutants, Tigrina mutants, Albina mutants, Xantha mutants, Chlorina mutants, Viridis mutants	Physical and chemical mutagens	Lethal chlorophyll mutants; reduced chlorophyll content; light green foliage phenotype;highest survival among chlorophyll mutants	[64]

altered responses to abiotic stresses such as drought, salinity, and temperature extremes. The diversity of mutant phenotypes highlights key physiological and biochemical pathways involved in stress adaptation. Importantly, these studies support the identification and functional validation of stress-responsive genes, thereby complementing primer design strategies and facilitating the development of stress-resilient chickpea varieties.

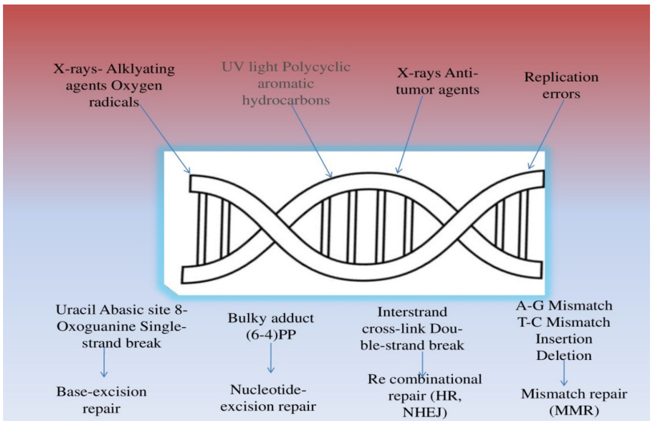

Figure 4 – DNA repair mechanisms and photoprotective pathways in plants under UV-B and abiotic stress.

6.6 Transgenic Approaches and ABA-Mediated Regulation

Under drought stress, endogenous ABA accumulates to control gene expression, additional transgenic strategies include genes encoding heat shock and LEA proteins as well as galactinol synthase (GolS) to enhance drought tolerance, with ABRE motifs regulating ABA-responsive genes such as RD29B in Arabidopsis [65, 66]. The overall DNA repair mechanisms and photoprotective pathways in plants under UV-B and abiotic stress are summarized in Figure 4.

7. CONCLUSION

This review highlights the responses and adaptive mechanisms of chickpea genotypes to UV-B radiation and their role in enhancing crop resilience. Importantly, UV-B has a dual role that should be clearly distinguished. As an abiotic stress factor, UV-B negatively affects plant growth, development, and key physiological and biochemical processes, primarily through oxidative damage and disruption of cellular functions. At the same time, when applied under controlled conditions, UV-B can serve as an effective mutagenic tool to generate genetic variability. Such induced mutations expand the genetic base of chickpea and support the development of stress-tolerant genotypes. Distinguishing between these two roles provides a clearer framework for the use of UV-B in both stress biology and mutation-based breeding under changing environmental conditions.

8. FUTURE RESEARCH DIRECTIONS

Future research should prioritize the development of crop varieties better suited to changing climates by exploring plant responses to UV-B radiation. Efforts should focus on identifying and enhancing heritable traits that improve UV-B tolerance, including antioxidant capacity, which mitigates cellular damage. Increasing levels of protective compounds such as flavonoids can further enhance stress resilience. Integrating genetic resources from traditional cultivars and wild relatives with modern gene-editing tools and conventional breeding techniques can produce more robust, stress-tolerant crops. Additionally, field studies are needed to understand the interactive effects of UV-B radiation with other environmental stresses, such as drought, high temperatures, and nutrient deficiencies. By combining advanced genetics with sustainable agricultural practices, it is possible to develop crops that remain productive, stable, and resilient under the challenges posed by climate change.

CONTRIBUTION OF THE AUTHORS

M.K. and K.A. contributed to conceptualization; M.K., K.A., A.A., and Z.S. performed formal analysis; K.A. provided resources; M.K. and K.A. wrote the original draft; M.K. performed writing-review and editing. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

OPEN ACCESS

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