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Plant Responses to UV-B Radiation

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Abstract

Ozone, a vital gas found in Earth's atmosphere, absorbs and filters ultraviolet (UV) light from the sun, protecting life forms from its damaging effects, especially in the 280–400 nm wavelength range. Exposure to UV-B radiation can seriously harm plants, resulting in morphological alterations, growth inhibition, and decreased biomass as a result of inhibited photosynthesis. Moreover, this radiation interferes with photosynthetic activities and lowers chlorophyll levels. The harmful effects of UV-B radiation on plants differ according to species, growing circumstances, and UV exposure level. Plants have evolved defence mechanisms in response to the harm, including heightened phenolic compound synthesis and strengthened antioxidant defence systems. Through the production of secondary metabolites that function as UV screens and antioxidants, these adaptations help lessen the effects of oxidative stress caused by UV-B. In order to address the problems brought on by ozone layer depletion and UV-B radiation exposure in agriculture and the environment, it is essential to understand the intricate impacts of UV-B radiation on plant physiology and defence mechanisms.

Keywords: UV-B radiation, photosynthetic pigments, secondary metabolites, morphogenesis, defence mechanism.

Introduction

Ozone, a gas found in Earth's atmosphere, is crucial for shielding living organisms from the harmful effects of the sun's ultraviolet (UV) radiation. The stratospheric ozone layer provides this protection by absorbing and filtering UV radiation, which ranges in wavelength from 280 to 400 nm. This radiation can cause severe damage to living cells, leading to skin cancer, cataracts, and other health issues in humans (Neale *et al*., 2023), as well as negatively impacting plants and marine ecosystems (Neale *et al*., 2023). UV radiation is divided into three classes based on wavelength: UV-A (315–400 nm), UV-B (280–315 nm), and UV-C (200–280 nm). The ozone layer absorbs almost all UV-C radiation, preventing it from reaching Earth's surface. While UV-A radiation is not absorbed by the ozone layer and does not significantly harm plants, UV-B radiation is partly absorbed and is the most detrimental to plants. Its intensity largely depends on the thickness of the stratospheric ozone layer.

UV-B radiation causes various harmful effects on plants, including morphological alterations, growth inhibition, and increased phenolic pigments (Sharma *et al*., 1998; Mackerness and Thomas, 1999; Hollosy, 2002; Brzezinska *et al*., 2006). It is a significant factor in physiological change and a decline in agricultural plant biomass due to photosynthesis inhibition (Vass, 1997; Agrawal *et al*., 2004; Ines *et al*., 2007). UV-B radiation has been revealed to result in shorter plant growth, reduced total biomass, decreased fresh mass and leaf area, and changed leaf morphology (Zuk-Golaszewska *et al*., 2011; Inostroza-Blancheteau *et al*., 2016; Yadav *et al*., 2020). Indirect damage from UV-B contact includes lower chlorophyll-a and b levels in *Phaseolus vulgaris* leaves (Michaela *et al*., 2000) and various physiological disorders, such as damage of photosynthetic pigments, thylakoid membrane integrity loss, decreased Rubisco enzymatic activity, and down-regulation of genes connected to photosynthesis (Jansen *et al*., 1996; Hollosy, 2002).

The effects of UV-B radiation on plants vary depending on factors such as species and cultivar sensitivity, growth conditions (chamber, greenhouse, or open field), growth season (Jordan, 1996). UV-B exposure intensity and duration (based on UV lamp type), exposure system and setup, availability of visible light, and the action spectra used to calculate biologically effective UV-B radiation (Rundel, 2006). Current studies focus on the multifaceted roles of UV radiation, including its acclimatory and regulatory functions. Plants adapt to the damaging effects of UV-B radiation by repair mechanisms and enhancing protective mechanisms and through regulatory systems (Inostroza-Blancheteau *et al*., 2016; Piccini *et al*., 2020). Photosynthetic organisms have developed UV-B protection strategies, such as

thickening dermal tissue to shield photosynthetically active mesophyll and increasing wax and trichome production on their surfaces (Cen *et al*., 2006). The production of different phenolic compounds through the biosynthesis of secondary metabolites requires the phenylpropanoid pathway. In plant cells exposed to ultraviolet light, flavonoids—a kind of low-molecular-weight phenolic chemical—are more prevalent. Higher activity of phenylalanine ammonia-lyase (PAL), the key enzyme for flavonoid production, correlates with increased flavonoid concentration under UV exposure. Anthocyanins, a type of phytopigment, provide vibrant colours to many plant tissues, aiding plants in adapting to abiotic stresses and maintaining their health and nutrition.

UV-B exposure-induced lipid peroxidation and excess reactive oxygen species (ROS) can be tolerated by plants with improved or upregulated antioxidative defence systems, including enzymatic and non-enzymatic (Rai *et al.,* 2011; Jaiswal *et al.,* 2020). Several research (Schreiner *et al.,* 2012; Yadav *et al.,* 2020) have reported the induction of secondary metabolite synthesis under UV-B supplementation and proposed its protective effect against UV-B stress. By boosting the generation of ROS such as hydroxyl radicals (OH•), hydrogen peroxide (H_2O_2), and superoxide anion (O_2-), UV-B light puts plants under oxidative stress. Enzymes including glutathione peroxidase (GPX), ascorbate peroxidase (APX), catalase (CAT), and superoxide dismutase (SOD) are important antioxidants that contribute to an antioxidant system that shields plant cells from reactive oxygen species (ROS). The accumulation of these reactive species leads to oxidative stress, damaging various cellular components (Zhang *et al*., 2018; Bhattacharjee, 2019).

Plant's ability to produce secondary metabolites including alkaloids, phenolic acids, and flavonoids is impacted by UV-B light. These compounds are crucial for plant defence and adaptation to environmental stress. When exposed to UV-B radiation, plants activate specific biosynthetic pathways, increasing the levels of these metabolites. This boost aids in countering UV-B damage by providing antioxidant protection, repairing damaged molecules, and acting as UV screens (Shi and Liu, 2021). UV-B radiation can alter the concentration of desirable molecules and the overall secondary metabolite profile, potentially impacting other primary and secondary metabolites. These compounds are integral to plant defence mechanisms, providing antioxidant protection, repairing damaged molecules, and serving as UV screens. Understanding the multifaceted effects of UV-B on plant physiology is crucial for developing approaches to mitigate the negative impacts of ozone layer depletion on agriculture and ecosystems. This knowledge can help enhance plant resilience and maintain ecological balance in the face of changing environmental conditions.

Response to Plant Morphological changes

Plants that are exposed to high UV-B radiation levels experience a number of common morphological alterations. According to Robinson *et al.,* (2015) and Hayes (2017), UV-B radiation has a detrimental effect on plant growth and morphology, resulting in decreased plant height, leaf area, and dry weight as well as increased branching and leaf curling. The reduction in leaf area, which is brought on by UV-B radiation's harm to photosynthetic pigments, is one of the biggest alterations. These pigments are essential for light capture and photosynthesis, so their damage results in a diminished leaf surface area, lower photosynthetic capacity, and consequently, reduced growth and productivity.

In response to UV-B exposure, plants develop several defence mechanisms to mitigate damage. One such mechanism is leaf thickening, which increases the path length of UV radiation within the leaf tissue. By thickening their leaves, plants can absorb and scatter more UV radiation before it penetrates deeper, thereby protecting vital cellular structures from UV-induced damage. Additionally, exposure to UV radiation leads to increased cuticular wax deposition. Broadleaf plants are generally more sensitive to UV radiation than narrow-leaf plants, with members of the Cucurbitaceae and Brassicaceae families being particularly vulnerable (Kakani *et al*., 2003). While plants can tolerate certain levels of UV-B radiation and light intensity, their tolerance varies by species, age, and exposure duration. If UV-B exposure exceeds these tolerance limits, changes in leaf anatomy and decreases in biomass occur.

Increased UV-B exposure can also lead to other morphological changes such as leaf curling or cupping. This occurs due to the conversion of the plant hormone indole-acetic acid (IAA) into 3-methylene oxindole, causing differential growth rates within the leaf. The upper side of the leaf grows less than the lower side, resulting in leaf curling or cupping as they develop (Ros and Tevini, 1995). Increased branching and tillering, or the development of new shoots or stems from the base of the plant, as well as an overall increase in leaf count, have also been seen in plants exposed to high UV-B levels. Though these adaptations may appear advantageous in spreading the danger of harm, they frequently result in fewer fruits and flowers being produced, along with a decline in the strength of the seedlings. The overall decrease in biomass build-up and reproductive success has the potential to have a major effect on agricultural yields and quality.

Photosynthetic response

Essential photosynthetic pigments, including as chlorophylls and carotenoids, which are vital for absorbing light energy and shielding the photosynthetic machinery from oxidative damage, are reduced in concentration when exposed to UV-B radiation. This decrease

diminishes the plant's ability to absorb light and increases its susceptibility to photo damage. Carotenoids serve as antioxidants and pigments that absorb light, while chloroplasts require chlorophylls for photosynthesis. Interestingly, the *Olivastra seggianese* variety is unaffected by UV-B treatment in terms of chlorophyll a, b, β-carotene, and lutein responses (Piccini *et al*.,2021). Conversely, UV-B inhibits pigment build up in the *Giarraffa* variety, indicating an adaptive mechanism to guard against overexposure to UV-B radiation. This decrease in pigment content may also signify UV-B radiation-induced deterioration, as observed in *Bryum argenteum, Prunus dulcis,* and *Oryza sativa* (Piccini *et al*.,2020*)*. Additionally, UV-B exposure compromises the structural integrity of thylakoid membranes within chloroplasts, which are critical for the light-dependent reactions of photosynthesis. Damage to these membranes impairs photosynthetic efficiency, as evidenced by changes in chloroplast ultrastructure, such as swelling and disorganization of thylakoid stacks. Because the photosynthetic apparatus is highly sensitive to UV-B light, photosynthetic efficiency is greatly impacted, inhibiting plant development and modifying the metabolism of carbon and nitrogen pathways (Kataria *et al*., 2013).

One primary effect of UV-B radiation is its impact on stomatal conductance, affecting water loss through transpiration and CO_2 assimilation. In-depth studies have revealed that UV-B radiation causes direct injuries to the photosynthetic apparatus, notably inactivating photosystem II (PSII), a key component of the photosynthetic electron transport chain (Kataria *et al.,* 2014). This inactivation disrupts the conversion of light energy into chemical energy, thereby reducing photosynthetic performance.

UV radiation, particularly ultraviolet-B (280-320 nm) in solar light, impacts various photosynthetic processes, including oxygen evolution, pigment synthesis, CO_2 fixation, and electron transport within the PSII system. UV-B radiation also affects Ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco), an essential enzyme in the Calvin cycle responsible for CO_2 fixation. Reduced Rubisco activity limits carbon fixation, often accompanied by the down-regulation of genes encoding photosynthetic proteins, further impairing photosynthetic capacity (Yu *et al*., 2013).

While some studies suggest that UV damage occurs at the catalytic Mn cluster of photosystems, others demonstrate that electron transport inhibition results from UV-A radiation damage to the QB quinone electron acceptor. Additionally, PSII is harmed by UV-B radiation as it modifies the QB binding site and affects the binding of plastoquinone, leading to a loss of function and blockage of the electron transport chain (Vass *et al*., 2005; Rastogi *et al*., 2014; Mohajer *et al*., 2015; Sompornpailin and Kanthang, 2015).

Photosystem II (PSII) is highly susceptible to UV light, particularly affecting the D1 and D2 proteins. Degradation of these proteins can inhibit electron transport and disrupt the reaction canter's functionality. The D1 proteins, core components of PSII, maintain the stability of the reaction center and provide binding sites for redox cofactors involved in electron transport, such as QB. Specifically, UV-B radiation triggers the degradation of D1 proteins, and repairing this damage heavily relies on the expression of the psbA gene (Chaturvedi *et al.,* 1998).

Studies have shown that the D1 proteins' vulnerability to UV-B radiation and the critical role of the psbA gene in repairing UV-B-induced damage are well-documented (Chaturvedi *et al.*, 1998). A study using real-time PCR techniques examined the relationship between the loss of D1 proteins under UV-B radiation stress and the inhibitory sites in QB. The findings indicated that exposure to UV-B radiation for 2, 4, and 6 hours significantly increased the expression of the psbA gene, suggesting an adaptive response (Mackerness *et al.*, 1997). However, after 12 and 24 hours of exposure, the expression of the psbA gene declined, implying that prolonged UV-B radiation causes photodamage that cannot be effectively repaired. Consequently, UV-B rays hinder electron transport pathways and decrease photosynthetic activity.

Furthermore, UV-B radiation can directly alter protein structure through photochemical processes. UV-B photons can be absorbed by amino acid residues within proteins, leading to the formation of photochemical products such as crosslinks, adducts, or modifications to amino acid side chains. These alterations can disrupt the native structure of the protein, affecting its function. In the case of PsbD and the 33 kDa protein, direct UV-B-induced damage may impair their ability to participate in photosynthetic reactions (Cai *et al.,* 2016).

Plants react to major abiotic stressors like UV-B radiation in various ways, which can impact their development, growth, and accumulation of secondary metabolites. According to Dotto and Casati (2017), Gupta *et al.,* (2018), González-Villagra *et al.,* (2020), Ding *et al.,* (2021), and other researchers, these responses involve several gene activities. Overall, the detrimental effects of UV-B radiation on the photosynthetic apparatus involve a variety of structural and functional impairments that result in altered metabolic processes, decreased photosynthetic efficiency, and ultimately decreased plant growth and output.

Response to Defence mechanism

Plants have evolved a number of defence mechanisms against UV-B radiation, including the production of UV-absorbing substances (like flavonoids), the activation of antioxidant enzymes (like catalase and superoxide dismutase), and the repair of broken

proteins. In reaction to UV-B radiation, plants release a range of secondary metabolites, such as flavonoids, anthocyanins, and other phenolic chemicals. Notably, plants unprotected to low-dosage UV-B radiation experience significant changes in their secondary metabolism, important to an increased accretion of phenolic substances such as flavonoids and glucosinolates (Schreiner *et al*., 2006).

The production of UV-B absorbing compounds such hydroxycinnamates, flavonoids, and flavanol, glucosides depends on the phenylpropanoid biosynthetic pathway. The first step in the process is the amino acid phenylalanine, which is changed into cinnamic acid by the enzyme phenylalanine ammonia lyase (PAL) by non-oxidative deamination. The initial precursor of the flavonoid biosynthesis pathway is then produced by 4-coumarate: CoA ligase (4CL) ligating p-coumaric acid with coenzyme A, after cinnamate 4-hydroxylase (C4H) catalyzes the hydroxylation of cinnamic acid to p-coumaric acid. Chalcone isomerase (CHI; TT5) further conjugates 4-coumarate-CoA with three molecules of malonyl-CoA, leading into the flavonoid biosynthesis pathway. Flavanone 3-hydroxylase (F3H; TT6) then converts naringenin to dihydrokaempferol. This compound is converted to kaempferol by flavanol synthase (FLS) and to dihydroquercetin by flavonoid 3'-hydroxylase (F3'H; TT7). Ultimately, dihydroquercetin is converted to quercetin by FLS. Distinct sugar-specific flavanol O-glycosyl transferases then glycosylate these compounds to produce quercetin 3-O-glucosides or kaempferol 3- or 7-O-rhamnosides (Jordan, 2016).

The amount and length of exposure to UV-B radiation greatly affect how flavonoids are made and stored in plant cell walls, vacuoles, and chloroplasts (Tilbrook *et al*., 2013). These compounds act as natural sunscreens, absorbing and dissipating UV radiation before it can penetrate deeper into photosynthetic tissues. Flavonoids, for instance, can absorb UV-B radiation in the range of 280-320 nm. By accumulating these compounds in their leaves, stems, and other exposed tissues, plants decrease the quantity of UV-B reaching critical cellular components, including photosynthetic proteins. High sunlight induces the synthesis and accumulation of flavonoids, with transgenic plants showing upregulation of genes accountable for flavonoid biosynthesis is below UV-B conditions (Ryan *et al*., 2002). Exposure to UV increases leaf flavonoids and anthocyanin production, with flavonoids having maximum absorption in UV light. UV-B may up-regulate several structural genes in the anthocyanin biosynthesis pathway, although the mechanism behind this increase has not been linked to a specific UV-B regulatory pathway. Flavonols, which are significant components of wine, contribute to its velvety astringency, color enhancement, and stability (Hufnagel and Hofmann, 2008). The VvMYBF1 transcription factor is a particular regulator of flavonol production in

grapevine, and UV-B regulates its expression in *Arabidopsis thaliana* (Rizzini *et al*., 2011). Research has demonstrated that environmental factors other than UV-B radiation can also enhance the biosynthesis of flavonols. In grape cells, sugar levels regulate a portion of the biosynthesis of flavonoids, making it more difficult to identify particular environmental stressors that affect ripening fruit (Ferri *et al*., 2008).

As UV-B absorbents, flavonoids reduce oxidative damage to cellular components by scavenging reactive oxygen species (ROS) produced during UV-B stress. This antioxidant activity helps maintain cellular homeostasis and preserves essential macromolecules like proteins, lipids, and DNA from UV-induced lesions (Ricci *et al.,* 2021). Additionally, flavonoids contribute to UV-B acclimation by modulating signal transduction pathways and gene expression related to stress response and DNA repair mechanisms. Due to their potential benefits for human health, flavonoids have drawn significant attention. Studies have shown that they are potent antioxidants (Tatullo *et al*., 2016), anti-inflammatory (Nile *et al*., 2015), cardioprotective (Mozaffarian *et al*., 2016), anticancer (Madunić *et al*., 2018), and antibacterial agents (Xie *et al*., 2012). UV-B radiation can trigger the generation of ROS within plant cells, important to oxidative stress and damage to biomolecules, including proteins (Dotto and Casati, 2017). To counteract this, plants activate their antioxidant defense systems, comprising enzymes such as superoxide dismutase (SOD), catalase (CAT), peroxidases, and glutathione peroxidases. SOD catalyzes the dismutation of superoxide radicals (O_2•−) into oxygen (O_2) and hydrogen peroxide (H_2O_2), while catalase and peroxidases detoxify hydrogen peroxide, preventing its accumulation and the subsequent formation of highly reactive hydroxyl radicals (OH). By scavenging ROS, these enzymes protect photosynthetic proteins and other cellular components from oxidative damage induced by UV-B radiation. This protection is critical for maintaining cellular integrity and function, enabling plants to continue their growth and metabolic activities despite exposure to potentially harmful environmental conditions. The efficiency and regulation of these antioxidant systems are essential for plant survival and adaptation, especially in environments with increased UV-B radiation due to ozone layer depletion.

Response of plant Secondary metabolites synthesis

UV-B radiation, a component of sunlight, serves as a double-edged sword for plants. While essential for various physiological processes like photosynthesis and morphogenesis, excessive exposure can cause cellular damage due to its higher energy levels. Plant physiology and UV-B radiation interact intricately, resulting in a cascade of responses at the molecular, biochemical, and morphological levels. The plant response to UV-B radiation includes the

modification of secondary metabolites (Höll *et al*., 2019). These metabolites, such as flavonoids, glucosinolates, terpenes, alkaloids, and phenolic acids, play pivotal roles in plant defence mechanisms against UV-B stress.

A comparative study examined the accumulation of phenolics following UV irradiation in buckwheat genotypes (*Fagopyrum esculentum* and *F. tataricum*), identifying a specific rise in quercetin concentration in *F. esculentum* (Regvar *et al*., 2012). Huyskens-Keil *et al*., (2007), Treutter (2010), and Schreiner *et al*., (2012) have reported on the elicitor properties of low UV-B radiation, such as phenolic compound buildup. Research has shown an increase in quercetin in onion bulbs, anthocyanins in strawberries (Higashio *et al*., 2005), as well as flavonoids in *Brassica sprouts* (Huyskens-Keil *et al*., 2008) and black currant fruits (Huyskens-Keil *et al*., 2007).Olive leaves contain a wide variety of phenolic compounds, such as flavonoids (luteolin-7-O-glucoside, luteolin-5-O-glucoside, luteolin-4-O-glucoside, quercetin-7-O-rutinoside, quercetin-3-O-glucoside, apigenin-7-O-glucoside, and chrysoeriol-7-O-glucoside),secoiridoids (oleuropein), derivatives of hydroxycinnamic acid (verbascoside), phenolic alcohols (like hydroxytyrosol and tyrosol), and phenolic acids (like chlorogenic and caffeic acids) (Nicolì *et al*., 2019; Talhaoui *et al*., 2015; Dias *et al*., 2020).

The phenylpropanoid-related metabolites shikimic acid, quinic acid, and phenylalanine were also significantly elevated in lemon balm (*Melissa officinalis*) exposed to UV-B irradiation for 2 hrs compared with control plants, according to global metabolite profiling of UV-induced changes (Kim *et al*., 2012). Broccoli sprouts' total glucosinolate concentrations were significantly increased by even modest UV-B exposure (0.3 to 0.6 kJ m^-2 d^-1). Global metabolite profiling of UV-induced changes revealed that lemon balm (*Melissa officinalis*) exposed to UV-B irradiation for 2 hrs had significantly higher levels of the phenylpropanoid-related metabolites shikimic acid, quinic acid, and phenylalanine compared with control plants (Kim *et al*., 2012). A mere 0.3 to 0.6 kJ m^-2 d^-1 of UV-B exposure was shown to dramatically boost the overall glucosinolate contents in broccoli sprouts (Pérez-Balibrea *et al*., 2010). A significant rise in the total glucosinolate content (~148%) of immature broccoli sprouts after UV-B (7.16 W/m^2) treatment was also recently reported by Moreira-Rodríguez *et al*., (2017). On the other hand, Wang *et al*., (2011) observed a noteworthy reduction in total glucosinolate in *A. thaliana* following a 12 hrs continuous exposure to UV-B. *Stereum hirsutum* sterol and fatty acid compositions were altered by UV radiation exposure, and the amount of antioxidants increased (Torres *et al*., 2016). According to a study by Fátima Rosane *et al*., (2018) on aquatic plants like *Alternanthera sessilis*, UV-B exposure for 8 hrs resulted in the greatest estimated flavonoid levels, which then recovered over a 24 hrs period. While retaining

the leaf's capacity to absorb photosynthetic energy, a variety of phenylpropanoid derivatives show preferential absorption in the UV-B band of the spectrum (Winkel-Shirley, 2001). This characteristic, along with their antioxidant capacity, makes plant phenolics ideal for UV protection. The fact that this reaction is dose-dependent implies that plants control the synthesis and build-up of secondary metabolites in response to the amount and duration of UV-B exposure. For instance, spherical vegetables and fruits require higher irradiance to induce metabolic alterations, showcasing the adaptability of plants to environmental stressors.

Ramani and Jayabaskaran (2008) found that in *C. roseus* suspension cultures, UV-B light enhanced the production of catharanthine and vindoline. When exposed to UV-B, *C. roseus* hairy roots produced more total terpenoid indole alkaloids (TIAs) (Binder *et al.,* 2009). Excessive artificial UV-B radiation altered the antioxidant composition of *Turnera diffusa* plants grown *in vitro* by increasing the amount of vitamin C and decreasing the amount of phenolic compounds (Soriano-Melgar *et al*., 2014). Among the secondary metabolites, flavonoids have garnered considerable attention due to their diverse roles in UV-B tolerance. The coordinated signal transduction pathway that begins with UV-B detection by the UVR8 receptor and activates transcription factors like HY5 to enhance the expression of the CHS gene is responsible for the UV-B-mediated activation of chalcone synthase. The CHS enzyme catalyzes the first step in flavonoid biosynthesis, resulting in the production of compounds that protect the plant from UV-B-induced damage. This process underscores the sophisticated mechanisms plants have evolved to cope with environmental stressors and maintain their health and survival (Binkert *et al*., 2014).

Mao *et al.,* (2017) reported that throughout the soybean's blooming and podding stages, increased UV light led to a significant increase in the levels of rutin, quercetin, and total flavonoids. Higher flavonoid content in wheat plants exposed to UV-B and irrigation deficit exacerbated the combined effects of both stress conditions (Feng *et al.,* 2007). UV-B modifies the phenylpropanoid and flavonoid pathways, changing the concentrations of glucosinolates and phenolic substances (Schreiner *et al*., 2009). According to Kaspar *et al*., (2011), there was a considerable rise in the concentration of saponin, a flavonoid with powerful antioxidant activity found in early green barley leaves, when exposed to UV-B light.

Terpenes, another class of secondary metabolites, also play a crucial role in UV-B protection. These isoprenoid compounds, including carotenes, xanthophylls, and other terpenoids, act as UV-B absorbents, attenuating harmful radiation and reducing its penetration into plant tissues. By absorbing UV-B photons, terpenes dissipate excess energy as heat, preventing photo-oxidative damage to cellular components. Many studies have examined the

effects of UV-B radiation on terpenoid indole alkaloids. For example, in *Catharanthus roseus*, varying levels of UV-B radiation led to the formation of strictosidine, vindoline, catharanthine, tabersonine, and ajmalicine (Rogers *et al*., 1996; Ouwerkerk *et al*., 1999). This is corroborated by the fact that when *C. roseus* leaves were exposed to extremely low UV-B light doses and intensities, tryptophan decarboxylase, a crucial enzyme in terpenoid indole alkaloid biosynthesis, became active (Rogers *et al*.,1996). Additionally, exposure to UV-B changes the makeup of fatty acids and sterols, which causes some plant species, like *Stereum hirsutum*, to accumulate antioxidants and improve their resistance to UV-B rays (Torres *et al*., 2014). According to Liu *et al.*, (2017), terpenoids are a large class of secondary metabolites that help protect plant leaves from the intense heat produced by UV-B radiation. There have been prior reports of a variety of plant species that are important for commerce and medicine, such as *Vitis vinifera, Cuminum cyminum, Curcuma caesia, Artemisia an*nua, and others, inducing the production of terpenoids in response to UV-B exposure (Ghasemi *et al*., 2019; Jaiswal *et al*., 2020; Li *et al*., 2021). In essence, the complex interplay between UV-B radiation and plant physiology highlights the multifaceted strategies adopted by plants to cope with environmental stress. By modulating secondary metabolite biosynthesis, signal transduction pathways, and cellular processes, plants adapt to fluctuating UV-B levels, ensuring their survival and productivity in diverse habitats.

Conclusion

UV-B radiation, influenced by the thickness of the stratospheric ozone layer, poses significant challenges to plant health and productivity. UV-B radiation leads to a wide range of detrimental effects, including morphological changes, growth inhibition, and reduced biomass. These adverse outcomes are mediated through various physiological disruptions, such as decreased chlorophyll levels, impaired photosynthetic processes, and increased oxidative stress. However, plants have developed adaptive mechanisms to mitigate UV-B damage, including the enhancement of protective secondary metabolites, upregulation of antioxidative defences, and structural modifications. These adaptive strategies underscore the complex interplay between UV-B radiation and plant physiology, highlighting the importance of understanding and addressing the implications of ozone layer depletion on agriculture and ecosystems. This understanding is crucial for devising strategies to boost plant resilience, sustain agricultural productivity, and preserve ecological balance amid environmental changes.

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