Innovations

Review: Relationship of UV Radiation with Plants Defense

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Abstract

The UV radiation comes from sun and reaches the earth surface and also composed of UVA, UVB and UVC and also filtered by the layer of ozone. Ultra violet radiation classified into three types namely UVA, UVB and UVC. The ozone layer becomes thin hence the UV radiation cannot penetrates into the earth surface, but nowadays the ozone layer concentration is decreased due to manmade activities, therefore the serious damages such as affecting elemental cycle, molecular level changes and also directly affected the earth global warming. At the same time UV act as a disease controller in plants. Since it's a new discovery, that the UV-B causes alter the in symptom and create the resistance to plants. In this review, concluding the recent knowledge about the effects of UV radiation on the pathological process in plants.

Keywords: *UVA, UVB, UVC, solar radiation, pathogen*

Introduction

The stratospheric ozone layer in air protects the earth from the sun's harmful ultraviolet (UV) radiation. Reduced ozone layer results in more UV radiation (UV-B in the range of 280~320 nm wavelength) reaching the surface of the earth. UV-A (315–400 nm) are less absorbed by the stratospheric ozone layer. The maximum part of UV-A radiation is able to reach the earth's surface and can cause tanning, skin aging, eye damage and immune suppression in animals; while, in plants, it can influence plant morphology, plus some specific effects (e.g. stomatal opening and induction of pigment formation). UV-B (280–315 nm) is strongly absorbed by the ozone layer but, if it reaches the earth's surface, it can contribute to snow blindness, sunburns, immune reductions and a variety of skin problems, including skin cancer and premature aging. In plants, it induces many morphological, physiological and molecular changes, including leaf structure alteration, antioxidative machinery and DNA damage. UV-C (100–280 nm) is completely absorbed by the ozone layer, so that the levels of UV-C radiation reaching the earth's surface are very small. However, it is lethal in nature and can change the expression pattern of genes in animals as well as in plants. Artificial UV-C can cause severe damage to exposed tissues.

UV-B role in plants

UV-B (280-315 nm) comprises one of the three classes of ultraviolet radiation and is positioned between UV-A (315-400 nm) and UV-C (100-280 nm) in the electromagnetic spectrum. The permeability of

the atmospheric ozone layer to UV radiation begins within the UV-B range of wavelengths. Hence, natural sunlight contains UV-A and a part of UV-B but undetectable levels of UV-C and UV-B below 290nm. Ultraviolet mediated induction of phenolic compounds is one of the most common described plant responses that can directly alter the feeding of herbivorous insects. UV-induced fluorescence in the yellow-green region of the spectrum (Schmelzer*et al*., 1988) quantitation of phenolic compounds in leaf extracts using spectrophotometry, chromatography and other techniques. Reduced growth may result from direct photochemical damage to key macromolecules such as proteins and nucleic acids or as an indirect consequence of the increased production of reactive oxygen species in plants exposed to UV-B. The degree of damage caused by UV-B should be strongly dependent on the efficiency of constitutive and UV-induced mechanisms of protection and repair, such as the accumulation of UV-absorbing sunscreens and the activation of antioxidant defenses. However, it is not yet clear whether the slight variations in levels of UV-absorbing compounds that are commonly detected among varieties of the same species or between plants subjected to different UV regimes are physiologically significant under field conditions. In parallel with this lack of information on the functional significance of natural variations in phenylpropanoid levels, there is a knowledge gap regarding the photo control of phenylpropanoid accumulation under field conditions. Mazza*et al*. (1999) reported that the solar UVB radiation caused reductions in leaf area expansion, biomass accumulation rate have been detected in various species. All of these methods have distinct advantages and limitations; a problem that is common to all of them is that they are time consuming and therefore have limited application in field studies that require multiple and rapid comparisons among genotypes or among plants subjected to contrasting light treatments. The chlorophyll fluorescence method can be used to estimate the transmittance of the epidermis in the UV region by comparing the signal obtained with UV irradiation with that induced by blue light. Chlorophyll fluorescence is a fast and sensitive technique to detect small differences in UV penetration to the mesophyll that is based on chlorophyll fluorescence imaging. Jansen *et al*. (1998) soybean (*Glycine max*) crops employed this technique with field-grown to test the hypothesis that UV-induced phenolic sunscreens provide effective protection to solar UV-B and to investigate the spectral sensitivity of the phenylpropanoid response induced by solar radiation under natural field conditions. UV radiation comprises of largely photobiological effects on both plants and animals due to its absorption by proteins and nucleic acids. As plants lack locomotion, adaptation or tolerance to increased levels of UV radiation is essential. Agricultural crops sensitivity to UV, Krupa*et al*. (1998) classified crop plants based only on crop dry weights, but several other crops physiological and growth parameters sensitive to UV were not addressed. UVB affects enzymatic antioxidants at both activity levels (Rao *et al*., 1996). Solar UVB affects many aspects of plant growth and metabolism. Multiple target sites for the action of UVB have been reported. Responses to elevated and ambient UV-B include increased DNA damage and antioxidant response (Mazza*et al*., 1999), alteration of plant morphology and architecture and lower biomass accumulation (Albert *et al*., 2005). The activities of antioxidant enzymes like superoxide dismutase; ascorbic acid peroxidase and glutathione reductase are enhanced by supplemental UV-B in *Arabidopsis* (Rao *et al*., 1996), cucumber (Jain *et al*., 2004). The potential harmful impact of increased UV-B intensity on ecological and biological systems has attracted global attention (Ballare*et al*., 2011). UV-B radiation induced oxidative injury and the impact on the antioxidant system have been studied on modern hybrid rice cultivars including lemon. Many studies have reported effects of strong UV-B radiation on the growth and physiological properties of crops, such as growth, plant morphology, photosynthesis, UV absorption substances, antioxidant systems, endogenous hormone regulation and yields (Kataria and Guruprasad, 2012). However, UV-B radiation affects local rice cultivars in the paddy field where plants are growing and the resultant oxidative injury and antioxidant systems responses from local rice cultivars have not been thoroughly investigated. Local rice cultivars have a long cultivation history and they are well adapted to the local environment. These cultivars normally have conserved genetic traits and are highly tolerant of stress factors in the area. Understanding how the antioxidant systems were altered in landraces when plants are subjected to long-term UV-B exposure in paddy field is very important to accurately evaluate and understand the effect of UV-B radiation on those

local cultivars. UV-B radiation will affect sustainability of those local cultivars in this area. Unfavorable environmental conditions lead to generation of ROS, which cause damage to cell membrane, protein and DNA. MDA has been used as a reliable biomarker for measuring oxidative injury level as the content is correlated to the level of super oxidation of membrane lipid (Liang *et al*., 2005).

Hence, UV-B can modulate the production of different plant chemicals varying in their effects on plant resistance. Likewise, the result of hydrolyzed compounds, i.e., mainly isothiocyanates and nitriles, possess high toxicity against some herbivorous arthropods (Jeschke*et al*., 2015). However, whether UV-B-mediated induction of glucosinolates, alone or in combination with flavonoids, is responsible for the enhanced resistance against those herbivores has not been fully addressed. These examples highlight the complexity of the interactions between the UV-B-induced chemical defenses and herbivorous arthropods. Nevertheless, we can speculate that the overlapping plant responses to UV-B and herbivore's attack might have a similar impact on plant defenses. For instance, this would be the case of common UV-B and herbivory-mediated induction of chlorogenic acid in *N. attenuata* plants (Izaguirre*et al*., 2007).The plant cells are affects fungal, bacterial or viral pathogens, fundamental processes such as photosynthesis, transpiration and nutrient acquisition may be compromised resulting in damage or death. Resistant plants ward attack by limiting the pathogen to small regions of tissue or individual cells where it may be killed by constitutive or activated defense components. Plants unable to mobilize such defenses will succumb to infection and die.

Photosynthetic pigments

Variation in the Chl reduction among crop species can also be attributed to UV-B radiation doses (2.6 - 49 kJ/m^2/day) and the light regimes (PAR) of 150-1800 mol/m^2 /s. This variation in PAR/UV-B ratio is also known to alter the extent of damage caused by UV-B radiation to crop plants. Reduction in Chl content was due to a breakdown of the structural integrity of chloroplasts on exposure to UV-B radiation. The Chl components, thylakoids and grana were sensitive to the incoming solar radiation (He *et al*., 1994; Tevini*et al*., 1991). An increase in UV-B radiation resulted in rupture of the thylakoids and grana due to the disintegration of the membranes. Photobleaching was dependent on the length and intensity of UV-B (Huang *et al*., 1993). Photosynthetic pigments can be destroyed by UV with comparative loss of photosynthetic capacity (Jordan *et al*., 1994; Rai*et al.,* 1995). Musil (1996) reported that UVB exposure of *Dimorphothecsinuata* reduced plant growth vigor, Chl, carotenoids, aminoacid, protein and total sugar and starch contents. A different observation was made by Mizubuti*etal*. (2000) where Chl and carotenoid level decreased initially during *Phytophthorainfestans* infection but later increased under solar UVB. Estevez *et al.* (2001) were of the opinion that UV-B radiation led to damage of Chl and photosynthesis which is due to generation of free radicals in thylakoids as a result of oxidative stress. The molecular target sites of UVB have been reviewed by many authors and all the reports emphasize the susceptibility of PSII as the vulnerable site for UVB (Savitch*et al*., 2001). De Menezes*et al.* (2015) reported that the direct solar UVB radiation killed the *Colletotrichumacutatum* conidia whereas short-term UVB treatment inhibited the germination of conidia. Kohler *et al*. (2017) have reported a decline in Chl*a*/*b* ratio, carotenoid content under UVB exposure in *Deschampsiaantarctica*, the first flowering plant discovered in Antarctic experiencing high levels of solar UVB. Recently, Falcon and Yanez-Mendiza (2019) have shown evidences for decrease in anthracnose infection in the seeds of *Lupinus* that were exposed to elevated levels of UVB and temperature.

The UVB exposure caused declining of the carotenoid content in cotton and bean seedlings but post-infective UVB was also helpful in altering the carotenoid content as compared to control. According to Mazza*etal*. (2000) and Laposi*etal*. (2002), plants overcome the stress response during the UVB radiation by overproducing proline, tocopherol and ascorbate contents (Carlettia*etal*., 2003). In Kentucky bluegrass treated with UV-B, total carotenoid content decreased over 10 days with recovery started occurring after 15

days of treatment.Suthaparan*et al*. (2012) reported that the powdery mildew caused decreased level of protein, glucose, Chl and carotenoids but UVB suppressed the growth of *Podosphaeraxanthii* in rose and cucumber. Janisiewic*etal*. (2015) reported that the imposition of dark period following 254nm UV radiation increased the resistance to *Podosphaeraaphanis*infection. Chl and carotenoid content decreased under powdery mildew attack but UV radiation enhanced the level of Chl and carotenoid content in several crop plants (Suthaparan*et al*., 2016)

Non- photosynthetic pigment composition

Anthocyanin accumulation was stimulated by various environmental stresses such as UV and blue light, high light, wounding, pathogen attack, drought, sugar and nutrient deficiency (Winkel-Shirley, 2001). The most common mechanism of protecting against damaging UV-B was the biosynthesis UV-absorbing compounds (Hahlbrock and Scheel, 1989). UV-B absorbing flavonoids were produced by *Poapratensis*in response to elevated levels of UV-B. Mostly these metabolites accumulate in the vacuoles beneath of the upper epidermal layers and in order to protect the chloroplasts housed in the mesophyll layers, these pigments help in attenuating the incoming UV radiation. Sharma *etal*. (1998) insisted that certain plants are more tolerant to UV-B as they overproduce a variety of secondary metabolites including flavonoids and anthocyanins. Enhanced amounts of UV-B not only affected plant development but also morphology and physiology (Matsuura *etal*., 2012). To counter the effects of UV-B, plants develop a wide range of strategies like increase in leaf thickness, leaf reflection and accumulation of secondary metabolites. The general function of anthocyanins is to attract animals and insects for flower pollination and seed dispersal but they protect plant cells from UV radiation (Chen *etal*., 2006). It was Shanthi and Janetta (2012) who showed that black gram was UVB tolerant than cluster bean when quantified under different monsoon periods. Santin*etal*. (2018) found an increase of anthocyanins, flavones and dihydroflavonols with increase in UVB dose.

Flavonoids are class of phenolics synthesized at the epidermal layers of leaves and tend to accumulate upon UV-B exposure.Atkinson *etal*. (2011) have shown that the combination of water stress and nematode infection resulted in altering the response of some secondary metabolites like flavonoids.Weber *etal*. (2013) identified individual phenolic compounds at different stages of *Colletotrichumsimmondsii* infection in *Fragaria* x*ananassa* and significant increase in flavonols with progress of infection. However, the presence of flavonoids and anthocyanin were known to show antioxidant activity in *Rhododendron* or other plant extracts (Saha and Verma, 2016). Thus it indicates that flavonoids and anthocyanin are not the major contributors of phenolics in the leaves and twigs of *Rhododendron* species since anthocyanin are more prevalent in floral regions. In mango, flavonoid accumulation was observed as resistance to a challenge of *C. gloeosporioides* infection and showed reduction in general decay (Sivankalyani*etal*., 2016). In apple, flavonols were significantly increased and the role of flavonols in defense against various pathogens was evident in *Gymnosporangiumyamadai* (Lu *etal*., 2017).Chakrabort*etal*. (2019) have demonstrated that in detached bean leaves, with the progression of *Colletotrichumgloeosporioides* infection, an increase in flavonoid content was evident.

Many of the compounds synthesized under UVB radiation, such as flavonoids (e.g., anthocyanins and flavonols), may have health promoting effects due to their antioxidant, antitumoral, cardioprotective and anti-inflammatory activities (Nassiri-Asl and Hosseinzadeh, 2009). In the present study, the flavonoids accumulated higher under UVB and phytohormone treatments. High temperature treatment was shown to decrease flavonoid content in grape berries (Mori *etal*., 2007). Most phenolic compounds, such as anthocyanins and flavonols, tend to accumulate in the last part of the development, where physical and biochemical changes takes place (Conde*etal*., 2007). In grape berries, increase in flavonol biosynthesis was

shown to be induced by environmental conditions other than UV-B (Koyama *etal*., 2012). Gregan*etal*. (2012) reported negligible levels of kaempferolglycosilatedflavonols in white-skinned grapes under exclusion of solar UVB.

Protein content

Alteration of photosynthetic pathway by UVB radiation has been reported by many authors. Among the target sites, PSII was considered to be the most vulnerable photosynthetic complex to UV-B stress (Kulandaivelu and Lingakumar, 2000). UV-B induced depression of photosynthesis that could be a result of the structural alteration of the D_1/D_2 polypeptide matrix without any detectable loss of the D_1 protein (Babu*et al.*, 1999). Delay of the D_1 protein loss than decline of photosynthetic activity in response to UV-B exposure may be due to the fact that the protein is linked by the radiation and rendered non-functional before it is degraded by protease (Aro*et al.*, 1993). In addition, UV-induced decrease of total protein content might be due to reduced photosynthetic performance resulting in decrease of nitrogen pool (Jordan, 1996; Vass, 1997). Selenium addition to the soil increased the protein content in soybean leaves even under ambient UV (Yao and Liu, 2007). Similarly, UV exclusion increased the number and size of nodules and leghemoglobin content of soybean (Chouhan*etal*., 2008). Kataria and Baghel (2016) ascertained that ambient UV radiation significantly reduced the soluble protein content whereas the same was increased by Se supply, indicating that Se supply diminished the detrimental effects of ambient UV-B on protein metabolism.

Amino acids

Yue*etal*. (1998) investigated that enhanced UV-B on plant nutrients such as glucose, aminoacids and proline drastically increased under field conditions. Another reason for the degradation of seed quality might be that UV radiation causes modification and destruction of aminoacids and disulfide groups which are strong absorbers of UV (Hollosy, 2002). Foyer and Noctor (2005) reported that the pretreatment of lupin seeds with UV-B dose of 2.83 or 3.75 kJ/ m^2 at 76°C was found to increase peroxidase activity. Tchameni*etal*. (2011) demonstrated that arbuscularmycorrhizae colonization led to a significant increase in the aminoacid content. Accumulation of aminoacids after colonization increased disease resistance. AM fungi treated plants showed an increase of aminoacid levels, which was the main factor in delaying lesion development under *Phytophthoramegakarya* infection in cocoa (Martinez-Lusche*etal*., 2014). UVB radiation modified the contents of aminoacids and total proteins which increased significantly in order to resist stress conditions. According to Kohler *et al*. (2017), the free aminoacid content was decreased under UVB exposure in *Deschampsiaantarctica*. Falcon and Yanez-Mendiza (2019) emphasized that solar UV-B and temperature play a major role for *Colletotrichumacutatum* infection. Fu *etal*. (2021) studied the effects of short-term UV-B on growth, physiology and metabolism of *Porphyrahaitanensis*. UV-B treatment was found to reduce the growth with bleaching. The contents of total aminoacids, soluble sugar, total protein and mycosporine-like aminoacids (MAAs) increased under different UV-B radiation intensities.

Proline

Generally, UVB treatment has been reported to cause accumulation of proline content as reported by Chai *et al*. (1998). Similarly, seedlings of rice and mungbean accumulated proline in the shoots when exposed to UV (Saradhi*etal*., 1995; Alia *etal*., 1997). Furthermore, UV exposure reduced the proline content in *Phaseolusmungo* and *Dimorphothecsinuata* (Britto*etal*., 1995;Musil, 1996). Accumulation of free proline in several plant species is regarded as a general response to stress from different origins (Sumaryati *et al*., 1992). Free proline increased under salt, cold (Chu *etal*., 1976), water and osmotic stresses (Karamanos*etal*., 1983). There are three possible causes of the free proline accumulation: firstly, stimulation of proline synthesis from glutamate (Barnett and Naylor, 1966; Boggess*etal*., 1976) which is dependent on ABA

concentration (Stewart, 1980); secondly, inhibition of proline oxidation and thirdly, inhibition of protein synthesis (Stewart, 1973). According to Stewart and Lee (1974), proline is a substance inducing osmotic adjustment. Other researchers have suggested that proline is a source of energy, carbon and nitrogen for the recovering tissues (Singh *etal*., 1973; Blum and Ebercon, 1976). However, Hanson *etal*. (1977) considered proline accumulation to be a symptom of damage. The increase in proline levels noticed during osmoregulation under stress provide non-toxic sinks for carbon and nitrogen preservation (Lisa and Winicov, 1997). Moreover, Hediat*etal*. (2011) observed an increase in the level of proline with increase in UV-B exposure. Likewise, besides as an osmolyte, proline acted as an antioxidative defense molecule during stress (Kaur and Asthir, 2015).

Conclusion:

In this review concluded the effects of UV role in plants based on the pigments composition (chlorophyll, carotenoids and anthocyanin and flavonoids) biomolecules (protein, amino acids,proline) after pathogen interaction. In healthy plant UVB radiation cause the damage to the morphology likewise infected seedlings. Furthermore, UV-B radiation followed by darkness appears to be more efficient than daytime applications, probably also due to the direct effect of UV-B light on the pathogen. Research on a pulsed UV-B treatment is scarce, but pulsed UV-B radiation could decrease the phototoxic effect. Furthermore, priming plants before an actual infection appears to be more efficient than using UV-B light as a direct tool to treat diseases or herbivory. Altogether, supplemental UVB radiation has a huge potential beneficial effect on plant defense, but the multifaceted modes of application will determine the actual success or failure of a certain UV-B treatment in crop protection.

Abbreviation

UVB-ultraviolet

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Contributions

All authors contributed to the study conception and design. RK and RM conducted the experiments and has written the manuscript. RK contributed in survey and sample collection. RK supervised and conceptualized the whole research project, also along with RM edited the manuscript. All authors read and approved the final manuscript.

Ethics declarations

Conflict of interest

The authors declare no conflict of interest.

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