UV-B and Crop Research from Past to New Age

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Abstract

UV-B is electromagnetic radiation from the sun with medium waves, most of which is absorbed by the ozone layer. It covers only a small part of the electromagnetic spectrum, but has a disproportionately large photobiological effect. The biological effects of UV light are greater than the simple heating effects, and many practical uses of UV light result from their interaction with organic molecules. UV-B radiation that interacts with biological systems has several specific cellular targets that result in adverse reactions. Both plants and animals are severely affected by increased UV-B radiation, but the susceptibility of plant species to UV-B radiation varies greatly. Plants adapt to changing environmental conditions and seek to develop some adaptive response. A large understanding about the effects of UV-B radiation on plants was established from research on economically important crops. The effectiveness of UV-B radiation was strongly influenced by common microclimate factors such as precipitation patterns and temperature. Ongoing field research suggests that they respond to UV-B radiation by increasing the levels of needle flavonoids, even under the full solar spectrum. Plants have developed natural adaptations such as anatomical, morphological, and biochemical changes that protect them from UV-B radiation. The degree of these natural adaptations may be related to the geographic origin of the species. This chapter describes the basics of UV-B, how it reaches the surface of the Earth, and its impact on the biological elements of the environment. So far, "UV-B" has been perceived as purely harmful to the environment. However, recent technological advances have changed the perceptions in UV-B research. It is now

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focused on how UV-B is beneficial to crop productivity and agriculture. This chapter provides comprehensive insights into the current status of UV-B research and deals with progress from past to present.

Keywords

Ultraviolet radiation · Plant production · Growth and development · Plant hormones · DNA damage

6.1 Introduction

There are many spectrums of radiation generated from the Sun light which reaches the Earth. Ultraviolet radiations have already been defined in the previous chapters as invisible spectrum of solar radiation that is determined as an electromagnetic measurement. There are three types of this UVR, of which UV-A and UV-B are the center of research attraction. About 5% of the terrestrial radiation of the midday sun is UVR, of which 95% accounts for UV-A and 5% for UV-B and UV-C. Out of this, most of the UV-B and UV-C are expelled from extraterrestrial radiations by stratospheric zone. The three types of radiation mentioned above have wavelengths: UV-A (315–400 nm), UV-B (280–315 nm), and UV-C (100–280 nm), respectively (Gueymard 2012). Although the maximum UVR of sunlight is filtered by the ozone layer of the stratosphere, so that only UV-A spectrum reaches the Earth. Studies done in the last few years revealed that in addition to UV-A some amount of UV-B also reaches the Earth and this UV-B is the main source of interference in terrestrial and aquatic ecosystems (Schmalwieser et al. 2018).

Although the UV-B and UV-C spectrum is taken up by the ozone surface and other gases present in the stratosphere, a very small amount of UV-B reaches the Earth. But for the last few years, due to the degradation of the ozone layer in the stratosphere, the amount of UV-B reaching the Earth has also increased (Molina and Rowland 1974). Since the minimum amount of UV-B is capable of interfering with biological systems, increasing amounts of UV-B can puts serious effects on biological systems.

Human population spread throughout the world depends on agricultural products for its nutrition and livelihood. Cereals, pulses, fruits, and flowers prominently figure these agricultural products. Due to direct contact with the surrounding, various biotic and abiotic components affect the crops directly or indirectly (Satterthwaite et al. 2010; Pandey et al. 2017; Capstaff and Miller 2018; Gull et al. 2019). Abiotic components are mainly physical factors such as temperature, air, water vapor, exposure, light and radiation, etc. All these factors play an important role in affecting the physiology of the crop species (Charrier et al. 2015). UVR affects all three of the plants, animals, and microorganisms; since plants are a major component of terrestrial ecosystem and are also the principle absorbers of sunlight, UVR has a maximum effect on their genetic makeup and physiology (Bais et al. 2018; Bornman et al. 2019).The importance of plants in UVR research also increases manifold because the phenomena of converting light energy into chemical energy can only be achieved by plants. As we know, a large population of the world depends on plants for food and economic support; hence, successive efforts for crop improvement and crop-related research need to be done continuously so that the availability of crop products is maintained sustainably. In the last few years, a lot of progress has been seen in scientific research related to plant products of agricultural importance, and along with this, the effects of UV-B on crops have also been observed in many species like rice, maize, soybean, chickpea, etc. (Raza et al. 2019; Begum et al. 2019).

Since this is an important aspect, it is necessary to know what exactly UV-B does to the plant physiology, or which physiological process of plants was mostly affected due to UV-B exposure?

We know that the process of photosynthesis in plants depends on light, and UV-B is a type of light radiation, so basically the center of focus for most researches is to study the effects of UV-B on photosynthesis and its subsequent metabolic fate (White and Jahnke 2002; Suchar and Robberecht 2016). In past years, many important scientific studies and research related to UV-B-mediated alteration in photosynthetic physiology of plants, molecular genetics, plant ecology, primary and secondary metabolism, etc., have been done specially focusing on crop production and stability (Bita and Gerats 2013; Kumar et al. 2017; Durairaj et al. 2018). **Presented chapter includes the report of past, present work done, and future studies to be conducted in relation to UV-B and plant responses as well as future researches in this field.**

6.2 UV-B, Plant Growth, and Development

Plant growth and development not only depend on the intrinsic and biotic factors, but it is also affected very much by abiotic factors too. Solar UV-B can potentially affect plant growth parameters such as seed germination, morphological characteristics of root, shoot, leaf, and its area, etc. UV-B doses behave differentially in plants species to species. Furness et al. (1999) demonstrated dose-dependent effects of UV-B on three weed species as decrease in leaf, stem, and root fresh weights, leaf area, and leaf: shoot ratio, while increase in shoot dry matter content, specific leaf weight, and leaf greenness of Cynoglossum officinale seedlings, in Centaurea diffusa Lam., leaf, stem, and root fresh weights, leaf area, and leaf: shoot ratio was increased, and no effects were observed in shoot dry matter content, specific leaf weight, and leaf greenness, and change in Trichome abundance and orientation was observed in Tragopogon pratensis L. A decrease of plant height, fresh mass of leaves, shoots and roots as well as leaf area with the curving of leaves was also observed in *Avena fatua* and *Setaria viridis* while exposing to different doses of UV-B radiations (Golaszewska et al. 2003). Similarly, dose-dependent effect of biologically effective UV-B was also reported for alteration in in chlorophyll content in Dwarf shrubs Bilberry (*Vaccinium myrtillus L.*) and cowberry (*Vaccinium vitis-idaea L.*), while *Vaccinium myrtillus* was found less sensitive than *Vaccinium vitis-idaea* as permanent discoloration was seen in later species

(Ştefănescu et al. 2020). Zhang et al. (2019) demonstrated the inhibition of root growth and related parameters (total root length, root surface area, root volume, average diameter, root tip number, and root dry weight) in soybean seedlings due to elevated levels of UV-B radiations. Shaukat et al. (2013) reported reducing effects of UV-B exposure on germination, seedling growth, and biochemical responses of *Vigna mungo (L.)* Hepper with increase in germination velocity, decrease in final germination, decrease in seedling growth and chlorophyll content. Kakani et al. (2003) stated the altering effects of UV-B on vegetative and reproductive morphology of field crops, and later on Raja Reddy et al. (2003) reported that enhanced UV-B exposure affects cotton plant at the level of morphology and anatomy both. Similar observation were made by Jansen et al. (2012) stated that UV-B exposure decreases the plant biomass as shorter petioles and shorter, narrower, and/or thicker leaf blades were formed in Arabidopsis thaliana. UV-B-mediated alteration in three cultivars of soybean was reported by Liu et al. (2013) at the level of pod number per plant and seed numbers per pod, while seed numbers were not affected by exposure. Despite being negatively impacted on plant growth and development, UV-B can positively influence the growth in some plant species as described by Bernado et al. (2021) in *Coffea arabica and C. canephora* cultivars which showed anatomic adjustments at the leaf scale such as increases in stomatal density at the abaxial and adaxial cuticles and abaxial epidermal thickening. Effect of UV-mediated plant morphological alteration also leads to the change in insect herbivory. Caputo et al. (2006) reported alteration of attractiveness in Arabidopsis plants to diamondback moths oviposition and changes in jasmonic acid pathways. Metwally et al. (2019) reported significantly increased vegetative morphology in in vitro cultivation of Spathiphyllum plant under increased UV radiation treatment. Farokh et al. (2010) reported the impact of UV-B on the seed germination and root morphology of Safflower plant. Pre-treatment of Cantaloupe type melon seeds of cultivar "Topmark" with UV-B impacts on the morphological characteristics after cultivation reported by Sosa-Flores et al. (2014). All of the above evidences indicate that UV-B exposure differentially affects the morphological characteristics of different species of plants.

6.3 UV-B and Plant Biochemistry

Solar UV-B affects the biochemical levels of plants upon irradiation and it causes changes in different biochemicals and secondary metabolites. As a biologically active radiation, UV-B is absorbed at an extent of 90% by leaves and subsequently puts deleterious impacts over biochemical responses in plants (Miller et al. 1994; Rao et al. 1996; Ambasht and Agrawal 2003). The experiments conducted on field-grown soybean crops by Mazza et al. (2000) revealed that there is an increase in phenylpropanoid content in leaves pretreated with solar UV-B in reference to the UV-B-induced cyclobutane pyrimidine dimer formation in leaf tissues. Similarly, combined yield decreased, and biomass production effect of increased UV-B and nitrogen fortification was seen in the simulation experiment on maize plants at a 20%

stratospheric ozone depletion over Portugal (Correia et al. 2000, 2012). Enhancement of differential flavonol glycosides content in nine populations of white clover (*Trifolium repens* L.) under the influence of increased UV-B exposures was recorded by Hofmann et al. (2000) through methane water extraction followed by high-throughput HPLC. In similar experiments, Pal et al. (1999) also reported the enhancement of flavonoid content in field crops under UV-B exposures and concluded that monocots are more protected against UV-B-induced alterations. Kakani et al. (2003) enlisted 128 studies on 35 field crop responses against photosynthetically active UV-B on various parameters like visual symptoms, leaf ultrastructure and anatomy, photosynthetic pigments, UV-B absorbing compounds, photosynthesis, growth and development, and yield, genotypic differences. Enhanced exposure of UV-B radiations alter leaf ultrastructure and biochemical accumulation in potato plants was reported (Santos et al. 2004) with increase in flavonoid content end elevation in Antioxidant enzyme levels. Biochemical sensitivity of rice plants under UV-B irradiation was reported (Dai et al. 1992; Hidema and Kumagai 2006; Yu et al. 2013). Differentially, UV-B-irradiated coriander *Coriandrum sativum L* plantlet showed an increased proline content while decreased photosynthetic pigments (chlorophyll a, chlorophyll b, and carotenoid) and total carbohydrate contents (Kumar and Pandey 2017). Choudhary and Agrawal (2014) reported negative effects of UV-B on the growth, biomass, yield, and its quality by generating oxidative stress directly or due to elevation of salicylic acid in two cultivars of Pea plant (Pisum sativum) with increased accumulation of flavonoids (quercetin and kaempferol) while neither protecting photosynthetic machinery nor helping in the elevation of biological nitrogen fixation. Biochemical alteration due to UV-B exposure also reported in some other species like two species of Vigna; *Vigna mungo (L.)* and *Vigna aconitifolia* (Jacq.) seedlings were tested at ambient and supplemental 280–320 nm dose of enhanced UV-B (Dwivedi et al. 2014) and shown accelerated generation of reactive oxygen species with increased positive response on antioxidants: superoxide dismutase (SOD) and guaiacol peroxidase (GPX) activity, and contents of proline, ascorbic acid, total phenolic contents (TPCs), and total flavonoid contents (TFCs) in leaves of both species. Schreiner et al. (2012) mentioned that low, ecologically relevant UV-B levels trigger distinct changes in the accumulation of, among others, phenolic compounds, carotenoids, and glucosinolates. Kataria and Guruprasad (2015) excluded solar UV-B in field experiments and observed improved photosynthetic performance and yield in four varieties of wheat *Triticum aestivum* with a remarkable increase in carbonic anhydrase, Rubisco, and nitrate reductase activities. The effect of biologically active UV-B was also investigated in highbush blueberry [*Vaccinium corymbosum L. cv.* Brigitta and Bluegold] (Inostroza-Blancheteau et al. 2014), and subsequent alterations were observed in leaf thickness, anthocyanin, and total phenolic contents with an increased accumulation of chlorogenic acid. Oxidative stress-mediated inhibition in physiology of *B. napus* L. due to the exposure of ambient UV-B was also reported by Zhu and Yang (2015). So, UV-B acts as the eustressor in horticulture and agriculture crops (Neugart and Schreiner 2018). Several ethnopharmacological constituents like alkaloids, terpenoids, and phenolics etc., are present in various medicinal plants which are important from the therapeutic point of view. Medicinal plants were also tested for the biochemical and metabolic responses under UV-B exposures, UV-mediated generation, enhancement and accumulation of bioactive compounds and new phytochemicals, UV-B influenced enhanced antioxidant activities and also evaluated as filters of UV radiations (Kumari and Prasad 2013; Mejia et al. 2015; Takshak and Agrawal 2019; Zhang et al. 2017; Chen et al. 2018; Klein et al. 2018; Vanhaelewyn et al. 2020; Pandey et al. 2021). In the current scenario, experiments are conducted on crops like peach, cucumber, pigeon pea, rice, wheat, tomatoes, and holy Basil, etc., with a special focus on the metabolomics, genomics, and proteomics-based studies to evaluate the potential of UV-B exposure on plant physiology and biochemistry at molecular level like alterations in secondary metabolite such as terpenoids, phenylpropanoids, phytoalexins, and fatty acids (Lv et al. 2020; Santin et al. 2021; Yang et al. 2021; Palma et al. 2021; Gupta and Prasad 2021; Phuong et al. 2021; Fernández et al. 2021; Sakalauskaitė et al. 2013; Al Hamedi et al. 2021).

6.4 UV-B and Plant Hormones

There are two classes of UV exposure effects on plants: (a) photomorphogenic effects and (b) stress effects. Both of these effects depend on the control and interaction between hormone pathways. Discovery of UV-B-specific photoreceptor UV RESISTANT LOCUS 8 enables to understand the effect of UV-B on different hormonal pathways in different ways such as photochemical, affecting biosynthesis, transport, and/or signaling. The possible mechanism of action for the UV-B-mediated regulation of hormone is either by inhibition of growth-promoting hormone and enhancement of environmental stress-induced defense hormone (Vanhaelewyn et al. 2016). Yang et al. (2004) reported UV-B-influenced changes in the hormonal levels in the vegetative and reproductive tissues and subsequent alteration in morphological characteristics of Tomato plants. Fina et al. (2017) evaluated the impact of UV-B on the hormonal changes in Maize crop and reported the altered growth regulating factor with Gibberellin levels with inhibition in leaf growth. Effect of UV-B exposure on plant hormones was investigated for the different species of crops such as tomato, soybean, rice, wheat, Quinoa, and some medicinal plants, etc., at their different parts like roots and shoots (Mannucci et al. 2020; Mao et al. 2017; Pan et al. 2014; Mariotti et al. 2021).

6.5 UV-B and Photosynthesis

Plants use sunlight to drive the mechanism of photosynthesis. In some past recent years, the approach of UV-B to the Earth surface is increased and since UV-B is a biologically significant radiation, it affects the photosynthetic machinery of the different species of plants differentially. Since 1996, expansion of ozone hole is being a serious and alarming issue and for the same duration many plant species have been undertaken to understand the effect of increasing UV radiations on photosynthesis. Comparative study on different plant species in response to the UV-B exposure was reported by Tevini et al. (1981, 1983, 1991), Tevini and Teramura (1989) for the alterations in physiological functions, photosynthetic response, and pigment contents. As a model to understood the long- term effects of UV-B on photosynthesis, members of Chlorophyceae (Macroalgae) were studied (Altamirano et al. 2000) under in situ conditions. Although UV-B causes deleterious effects on plants but some intrinsic mechanisms can also able to protect the plant from damage such as Cuadra and Harborne (1996) showed in the experiment conducted on *Gnaphalium luteo-album* and revealed that surface increase in leaf surface flavonol content in response to the UV-B exposure, acts as a protective shield for plant against damage and subsequently increases the photosynthetic pigment content. Mishra et al. (2008) evaluated the combined effects of UV-B and dimethoate on the photosynthetic response and pigment content of Cowpea seedlings stage. Being biologically active radiation, UV-B causes alterations in the mechanism as well as the content of photosynthetic pigments in different species of terrestrial, desert, and aquatic plants at their different tissue levels like leaves and even in shoots (Cen and Bornman 1990; Panagopoulos et al. 1990; Buma et al. 1996; Sarghein et al. 2008; Ibañez et al. 2008; Juozaitytė et al. 2008; Salama et al. 2011; Abney et al. 2013; Sztatelman et al. 2015; Piccini et al. 2020). Presently, some targeted studies are under progress to ameliorate the effect of UV-B on photosynthetic pigments using nanoparticle- based systems (Kataria et al. 2019; Azadi et al. 2021).

UV-B directly affects the photosystem performances of different species of plants by decreasing the penetration of PAR, reduction in photosynthetic and accessory pigments, impairing in stomatal function and altering canopy morphology, and thus reduces the photosynthetic carbon assimilation indirectly. UV-B may incorporate to alter the cytochrome *f* content in Photosystem I with decreased ribulose-1,5-bisphosphate carboxylase (Rubisco) activity hydrolysis of ATP synthase photosystem II. Strid et al. (1990) reported altered physiology of Photosystem I and Photosystem II in Pea plants under UV-B exposure. Similar studies were reported by Sinclair et al. (1990) on soybean plants. Sicora et al. (2006) investigated the effects of UV-B on Photosystem II at molecular level and reported the primary UV damage at the catalytic Mn cluster of water oxidation and de novo synthesis of the D1 and D2 reaction center protein subunits to repair UV- induced damage in PS II. UV-B-induced photoinhibition of Photosystem II was demonstrated in winter wheat *Triticum aestivum L.* which is associated with the altered PS II photochemistry with subsequent antioxidants profiles and xanthophylls cycle (Yang et al. 2007). Many studies have been conducted to evaluate the effect of UV-B on the photosystems in different species of plants (Bouchard et al. 2008; Guruprasad et al. 2007; Pescheck et al. 2014; Kataria et al. 2020; Sen and Puthur 2020; Maher et al. 2021; Xue et al. 2021). Since, evaluation of UV-B as the damaging agent of photosystems is established and it was already known that UV-B causes decrease in crop productivity, so now it is a necessity to develop approaches to protect crops from UV-B- induced damage. The overall criteria by which plant protect themselves from UV-B-mediated damage, mainly by plant flavonoids, which are synthesized due to the activation of UV RESISTANT LOCUS 8 which is a UV-B receptor in plant genome. Currently, focus is being made on the strategies to protect the crop and enhancement of product yield by using some shielding techniques and evaluation of intrinsic factors for crop growth (Podolec et al. 2021a, b).

6.6 UV-B and DNA Damage

UV-B is known as an ionizing radiation, and upon exposure, it causes serious alterations in the genetic content of any organism which results in form of mutation that reflects in the traits and phenotypes of the affected organism (Gill et al. 2015). Since the biochemical and physiological constituents of cell are actually the products of gene expression, UV-B exposure causes gene-mediated alterations in the crops (Casati and Walbot 2003). UV-B damages nuclear and orgenellar DNA by inducing various DNA lesions like cyclobutane pyrimidine dimers (CPDs) generation and other photoproducts, as the major lesions pyrimidine pyrimidone dimmers are produced by UV-B, while oxidized or hydrated bases, single-strand breaks, and others are minor lesions (Ballaré et al. 2001; Takahashi et al. 2012). Ries et al. (2000) demonstrated the reduction in genome stability in plant using *Arabidopsis thaliana and Nicotiana tabacum* as a model system with increase in somatic DNA rearrangements' recombination by a strong induction of photolyase and Rad51 gene expression.

6.7 Conclusion and Future Prospective

Sustainable availability of crops is a key issue for current and future point of view. Day-by-day increase in pollution is leading the increased reach of UV radiations to the Earth which accounts damage to not only in animals but a major damage also causes in the crop-producing plants. In context to the increasing population, assured availability of adequate quantity of edible food for each and every individual is a crucial point in present scenario. Past studies suggested the damaging effect of UV-B on crops such as decrease in nutritional contents, low yield, etc.; in developing world, more advance practices like targeted crop breeding, transgenic, and UV-resistant plant production must be undertaken to cope with the UV-B exposure to assure the crop survival and yield enhancement.

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