The Secret Beauty of Ultraviolet Radiation in Plants

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Introduction:

Ultraviolet (UV) ray is an electromagnetic radiation with wavelengths ranging from 200nm to 400nm. The ultraviolet radiation is divided into three further components *viz* UV-A (320-400nm), UV-B (280-320nm) and UV-C (200-280nm). The energy possessed by each portion of the spectrum is inversely proportional to its wavelength so UV-C> UV-B> UV-A (Gavin *et al*., 2001). The amount of UV radiation reaches the earth's surface is 8-9%, where 6.3% and 1.5% are UV-A and UV-B respectively (Pablo *et al*., 2014). The harmful UV-C radiation is absorbed by stratospheric oxygen, ozone and other atmospheric gases (Hollósy F, 2002). However, the depth of penetration of UV rays into the skin increase with increasing wavelength. The ozone layer present in the stratosphere absorbs the ultraviolet radiation radiated from the Sun and its relevance to the biological system is limited.

Plant physiological response to UV-B radiation:

Exposure of plants to UV-B radiation induces the range of photomorphogenic response and lead to a change in plant architectures such leaf thickening, cotyledon curling, inhibition of stem elongation, axillary branching, shifts in the root–shoot ratio, increased flower number and minimise the UV-B damage (Jansen, 2002). UV-B induces transcript accumulation of genes involved in the synthesis of phenolic compounds (**Flavonoids, anthocyanin, etc.)**, antioxidant enzymes and repair of UV-B damage (Brown *et al*., 2005; Hectors *et al*., 2007; Favory *et al*., 2009). **Flavonoids** play multiple physiological functions in the plant including epidermal flavonoids, which absorb UV-radiation, protect the internal tissues of leaves and stems; sensitivity of flavonoid-deficient mutants of maize and *Arabidopsis thaliana* to UV-B radiation; flavonoids are potent scavengers of reactive oxygen species and thus prevent peroxidation of lipids (Dieter Treutter, 2006). Flavonoids are the important signals where microbes can sense and develop plant-microbe interactions. This interaction was seen in few non- leguminous plants and also a symbiotic relationship between plants and arbuscular mycorrhizal fungi (Ponce *et al*. 2004). This is a significant action of flavonoids in improving plant growth and fitness. Banana produce flavonoid in the form of flavan-3,4-diols which condenses tannins contain and banana become resist to nematodes (Collingborn *et al*. 2000). UV-B induce the production of flavonols in silver birch and grape leaves (Tegelberg *et al*. 2004).

In the grape skin of black-skinned cultivars, UV radiation induces **anthocyanin** pigments accumulation in the large amount (Berli *et al*., 2011; Kataoka *et al*., 2003). The anthocyanin has weak UV radiation absorption capacity, even though although acylation reactions convert them in better UV-screeners; (Agati *et al*., 2010; Woodall *et al*., 1998). Accumulation of stilbenes and volatile compounds in the skin of Malbec grapes is also improved by the UV received at high altitudes (Berli *et al*., 2008). The compounds induced by UV radiation in grapes improve berry and wine features such as aroma, astringency, colour and stability; and also increase tolerance to abiotic and biotic stressors (Jug *et al*., 2003). Pablo *et al*., 2014 suggested that UV radiation modulates secondary metabolism in the skin of *Vitis vinifera* L. berries, which affects the final composition of both grapes and wines due to the biosynthesis and accumulation of secondary metabolites of several phenylpropanoids, which are appreciated in winemaking and potentially consult cross-tolerance, were almost specifically triggered.

Relationship of Reactive Oxygen Species (ROS) with UV-B in plants:

Plants produce reactive oxygen species (ROS) like hydroxyl radicals, singlet oxygen, superoxide radicals and hydrogen peroxide when they exposed to high UV-B doses and lead to oxidative damage (A-H-Mackerness, 2000; Hideg *et al*., 2002). ROS scavenging in plants is mediated by enzymes with high antioxidant activity such as glutathione, ascorbate, vitamin C, D and pyridoxine (vitamin B6). However, these ROS molecules, signalling molecules that regulate the expression of several UV-B responsive genes (A-H-Mackerness *et al*., 2001). In the case of higher plants, UV-B plays a negative role in the photosynthesis by down-regulating the expression of photosynthetic genes. Teramura and Sullivan, 1994 reported that UV-B also lowering enzyme activity, damaging D1 proteins and photosystem II, reducing chlorophyll (Chl) contents and CO2 uptake. It is reported that UV-B reduce the growth through inhibition of cell division, decrease plant biomass and seed production (Jordan, 2002; A-H-Mackerness *et al*., 2001). UV-B induced stress responses have also parallels with the stress induced by other abiotic stress and pathogen attack (A-H-Mackerness *et al*., 1999,; Hideg *et al*., 2013).

Plant molecular response to Ultraviolet (UV) radiation:

The solar energy is the only energy utilised by the plants for their photosynthesis. Plants have multiple protein photoreceptors that can sense the light signal with precisely perceive fluctuations in the intensity, spectral quality, direction, timing and periodicity of incoming sunlight (Frankhauser and Staiger, 2002). *Arabidopsis thaliana* consist of five members of phytochromes (PHY A-E) which mediate responses to red and far red light (600-750 nm). UV-A is sensed by cryptochromes (CRY1 and CRY2), phototropins (PHOT1 and PHOT2) and the zeitlupe proteins (ZTLs) and UV-B is sensed by UV RESISTANT LOCUS 8 (UVR8) (Heijde and Ulm, 2012). Photoreceptors absorb the photons of light and initiate the cascades of signals that plays roles in the regulation of the genes expression to respond morphogenetic, metabolic, protective and repair mechanisms.

The induction of UV-B radiation to plant result in photomorphogenic responses. These responses are partially mediated by **UV Resistant Locus 8** (UVR8). Tryptophan (Trp) act as the chromophore of UVR8 and absorbs UV-B. Tryptophans, Trp 285 and Trp 233 are examples of the main UV-B chromophore (Christie *et al*., 2012; Wu *et al*., 2012). The UVR8, homodimer is broken and split into monomer when the UV-B is perceived by Trp 285 and Trp 233. The UVR8 monomer interact with E3 ubiquitin ligase Constitutively Photomorphogenic1 (COP1) (Rizzini *et al*., 2011). **Suppressor of Phy A** (SPA) with bind with UVR8-COP complex in the presence of Cullin4–Damaged DNA Binding Protein 1 (CUL4-DB1) (CUL4-DB1-COP1-SPA-CUL4–DDB1). The **UVR8-COP-SPA** complex helps in induction and stability of the transcription factor, **Elongated Hypocotyl5** (HY5) (Huang *et al*., 2013) and communication of the signal that activates gene expression and UV-B acclimation in plants (Favory *et al*., 2009).

Role of UV-B and UV-A in DNA damage and repair in plants:

Plant responses to UV-B are complex because numerous macromolecules (nucleic acids, aromatic amino acids, proteins, lipids and phenolic compounds) absorb UV-B photons (Jordan, 2002). UV-B photons have the highest energy of all wavelengths in sunlight and thus have the potential to cause cellular damage through photochemical reactions (Caldwell and Flint, 1994; Jansen *et al*., 1998; Ballaré, 2003). The high-energy UV-B photons can cause mutation by forming **cyclobutane-pyrimidine** (CPDs) and **pyrimidine (6, 4) pyrimidone dimers** (6-4 PPs). RNA polymerases cannot read through CPDs and 6-4 PPs and give negative effects in DNA replication and transcription since DNA and (Jansen *et al*., 1998; Frohnmeyer and Staiger, 2003). UV-B-induced DNA damage is repaired by a photoreactivation mechanism mediated by UV-A and the enzyme photolyase breaks the chemical bonds of cyclobutane rings were reverted in the present of blue light with favourable temperature. Nucleotide excision repair mechanisms in darkness and homologous recombination can remove CPDs and 6-4 PPs formations (Frohnmeyer and Staiger, 2003).

Plant response to UV-C radiation:

The plants induce certain photomorphogenic responses such as tissue damage (Bornman *et al*., 1986), induction of carotenoids and polyamines (Tevini and Teramura, 1989), damage to the photosynthetic apparatus, phototropism, ATPase destruction (Murphy, 1983), unscheduled DNA synthesis in pollen, and anthocyanin and flavonoid induction in parsley, sorghum, and peanut callus (Hashimoto *et al*., 1991). A recent study has shown the contrasting effects of UV-C irradiation of the leaves of several plant species on their antifungal activities. Guillaume Marti *et al.*, 2014 reported that during leaf metabolomics study using UV-C help to increase stilbene derivatives. And in the case of *C. antarctica* leaves resveratrol and piceid levels were strongly induced. In contrast, both flavonoids and stilbene polymers were upregulated in *Vitis* leaves. Furthermore, it is reported that UV-C and UV-B have opposite effects on carotenoid levels (Tevini *et al*., 1981) and anthocyanin levels (Hashimoto *et al*., 1991). Therefore, as a general rule, UV-C is not a useful model for physiological responses induced by UV.

Conclusion:

The absorption of UV radiation by the photoreceptors or chromophore and give significant photomorphogenic responses. This knowledge can be used in the horticulture practice to improve the quality and nutritive values of crops, post harvesting resistance of crops from pests and pathogens, etc. And also this practice can be used to produce essential plant's compounds that possess pharmaceutical properties.

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