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ULTRAVIOLET-B RADIATION : A POTENT ELICITOR OF PHENYLPROPANOID PATHWAY COMPOUNDS

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Abstract

Although no longer considered a stress factor due to the successful implementation of Montreal Protocol in 1987 and consequent reductions in ozone depleting substances, ultraviolet (UV)-B radiation (a direct consequence of stratospheric ozone depletion) levels are far from reaching their pre-1980 status. Plants have developed various protective measures to counteract the adverse effects of this stress factor. One of the important defence strategies of plants against UV-B radiation is the biosynthesis of enhanced concentrations of secondary metabolites. For the biosynthesis of these metabolites, the phenylpropanoid pathway is ubiquitous in plants. This pathway leads to the biosynthesis of various phenolic compounds many of which play an important role not only in plant adaptation and survival, but also in various aspects pertaining to human health and nutrition. This review presents an overview of the current UV-B scenario, its effects on plants, and the defence strategies adopted by the latter to counter this stress. It also highlights the effects of UV-B on plant phenolics and on various genes and enzymes of the phenylpropanoid pathway. Lastly, it touches upon the medicinal properties of various phenolic compounds and the futuristic studies to utilise UV-B as a potent elicitor of pharmacologically important phenolics.

Key Words : Human health; phenolic compounds; phenylpropanoid pathway; UV-B radiation

Abbreviations : 6,4-PPs- 6,4-photoproducts; ANS- anthocyanidin synthase; CFC- chlorofluorocarbon; CHS- chalcone synthase; CPDs- cyclobutane pyrimidine dimers; DFR- dihydroflavonol reductase; F3H- flavanone-3-hydroxylase; HCFC- hydro-chlorofluorocarbon; IFR- isoflavone reductase; IFS- isoflavone synthase; ODSs- ozone depleting substances; PAL-phenylalanine ammonia lyase; ROS-reactive oxygen species; UV-B- ultraviolet-B

1. Introduction

Solar energy is the key to life on Earth. Ultraviolet (UV) radiation of the solar spectrum has been conventionally divided into UV-A (320-400 nm), UV-B (280-320 nm), and UV-C (less than 280 nm) of which UV-A and longer wavelengths of UV-B are of biological significance. Depletion of the stratospheric ozone layer has caused higher levels of UV-B radiation reaching the Earth. Since higher plants lack locomotion and cannot move away from sunlight, they have developed mechanisms and structures to adapt to the changes caused by the surplus UV-B radiation reaching them. One such strategy is the production of higher amounts of phenolics which act as screening compounds and protect against oxidative damage due to UV-B. Since these compounds are synthesized via phenylpropanoid pathway, they are also called phenylpropanoid compounds. The studies on these compounds have revealed them to be vital factors for plant adaptation and survival and also from the perspective of human health. Hence, the objective of the present review is to highlight the importance of UV-B in eliciting these compounds in plants.

2. Stratospheric Ozone Layer and UV-B Scenario

The first reports on the stratospheric ozone depletion due to anthropogenic emissions of chlorofluorocarbons were put forward by Molina and Rowland in 1974 while the first documentation of the Antarctic ozone hole was made by Farman *et al* in 1985. Very soon after these alarming indications, Montreal Protocol on Substances that Deplete Ozone Layer was signed in 1987 to contain and limit the emission of ozone depleting substances (ODSs), which, according to the studies up to 2013 by Chipperfield *et al* (2015), has been quite effective in controlling ODSs emissions. Antarctic ozone hole was initially expected to recover by ~2050 obliterating UV-B as a potent stress factor influencing life on Earth. However, some studies prior to 2013 as well as some later ones depict a not-so-simple scenario. For instance, in 2012, Anderson *et al* found a link between changing climatic conditions and increased incidence of UV-B reaching the Earth due to increase in the frequency and intensity of thunderstorms which are capable of thrusting water molecules into the air up to the stratosphere whence the sulphate aerosols attract these molecules, and chemical reactions occur which destroy ozone. Bornman *et al* (2015) have in turn demonstrated that carbon release from the plant litter and soils due to UV-B might be instrumental in contributing to global warming. Moreover, Laube *et al* (2014) have detected and quantified three CFCs and one HCFC with unknown emission sources which are being destroyed very slowly in the atmosphere and may be instrumental in increased levels of UV-B reaching the Earth. Already, in 2006, predictions have been made that full ozone hole recovery is expected to occur by 2068 (as against 2050 as previously expected), and a significant decrease in the area in not expected to start to occur until about 2024 (Newman *et al*, 2006). More recently, NASA scientists have predicted the ozone-hole size to return to pre-1980 levels by about 2075 (NASA, 2015). Since the ozone hole depletion and UV-B levels are directly related, despite the restrictions on ODSs, UV-B is still considered a threat to all living organisms.

3. Plant Responses to UV-B: Effects and Counteractive Protective Measures

Photosynthesis is a vital process in plants which requires sunlight; consequently, plants are inevitably exposed to UV-B radiation as well. Plants may respond both positively and negatively to the environment and the stresses they encounter. High levels of UV-B are capable of influencing various aspects of plants like morphology, physiology, biochemistry, and molecular biology. The effects of UV B on plants are highly varied depending upon a number of factors like species and cultivar sensitivity, growth chamber, greenhouse, or open field conditions, season of growth, the intensity and duration of UV B exposure (according to the type of UV lamps used), exposure system and set up, as well as the availability of visible light, and the action spectra used for computing biologically effective UV B radiation (Runeckles and Krupa, 1994; Jordan, 1996).

Bronzing and glazing are the initial symptoms observed upon exposure of plants to s-UV-B, while chronic exposure to this stress results in chlorosis, necrosis, leaf desiccation and their early senescence (Strid and Porra, 1992; Reddy *et al*, 2003; Demkura *et al*, 2010). Glazing (due to the accumulation of waxy compounds; Teramura, 1983) and bronzing (possibly due to the accumulation of coloured pigments such as carotenoids and anthocyanins or due to oxidation of phenolic compounds; Teramura, 1983; Cline and Salisbury, 1996) can be regarded as defence mechanisms against UV-B as the plant tries to attenuate this radiation and prevent its excessive penetration into the leaf interior. Other symptoms such as leaf curling and cupping (due to partial destruction of the growth hormone indole acetic acid on the exposed surface) have been observed in *Cyanoglossum officinale* (Furness *et al*, 1999), *Avena sativa* and *Setaria viridis* (Zuk-Golaszewska *et al*, 2003), and *Passiflora edulis* (Cechin *et al*, 2012). This reduces the exposed leaf surface area to UV-B as a protective measure. Increase in leaf thickness, changes in the number and size of palisade and spongy parenchyma cells and decreased stomatal frequency are some of the common plant responses to UV-B (Bornman and Vogelman, 1991; Lingakumar and Kulandaivelu, 1993; Weston *et al*, 2000). This might be due to addition of spongy mesophyll cells and/or due to lengthening of palisade parenchyma cells or increased number of palisade parenchyma layers (Weston *et al*, 2000) and are instrumental in attenuating the penetration of UV-B radiation into the leaf.

Generalised morphological changes due to s-UV-B include reductions in plant height, leaf area, plant biomass, delayed seedling and flower emergence, alterations in biomass accumulation patterns, and reductions in crop yield. However, a number of studies with dissimilar results have been reported (Reviewed by Kakani *et al*, 2003). At the biochemical level, major changes caused by UV-B include enhanced production of reactive oxygen species (ROS) (capable of causing peroxidation of lipids, protein oxidation, and impairment of nucleic acids and enzymatic activities; Mishra *et al*, 2011), DNA damage (either direct via formation of cyclobutane pyrimidine dimers (CPDs) and pyrimidine (6-4) pyrimidone dimers (6,4-PPs) (Britt, 1996), or indirectly via ROS), damage to the photosynthetic apparatus (including pigments, thylakoid membrane, stomatal parameters, Rubisco, cytochrome b/f-, light harvesting-, and PSI- and PSII complexes; Strid *et al*, 1994; Nogués and Baker, 1995; Nogués *et al*, 1999), and production of secondary metabolites.

ROS induced oxidative stress is countered by various enzymatic and non-enzymatic antioxidants in plants which either directly scavenge ROS (e.g. superoxide dismutase) or utilize various molecules such as flavonoids and ascorbate as substrates (e.g. peroxidases) to achieve the same results (Noctor and Foyer, 1998). To counteract DNA damage due to UV-B, three basic photorepair mechanisms come into play, photoreactivation, excision, and recombinational repair (Britt, 1995; Taylor *et al*, 1996), while damage to the photosynthetic apparatus are countered by synthesizing new enzymes and proteins in lieu of the damaged ones, repairing the chloroplastic DNA, and restoring D1 and D2 protein activities (if only partially) (Greenberg *et al*, 1989a, b; Wilson and Greenberg, 1993), and synthesizing and accumulating phenolic compounds (Jansen and Van Den Noort, 1998). Hence, biosynthesis of various phenolic compounds and flavonoids serve both UV-B screening and UV-B defence functions.

Prior to their recognition as essential compounds in plant adaptation and survival, secondary metabolites (various phenolic compounds including phenolics and others) were considered to be 'waste products' of plants since they are not directly involved in plant growth and development. However, they are as vital as primary plant metabolites, if not more so, due to their roles in plant adaptation and survival. Some of their functions include attraction of insects as pollinators and seed dispersal agents, protection against herbivory, insect attacks and pathogens, as phytoalexins, UV-B screening compounds, and growth hormones, stimulation of root nodule formation, and as signalling compounds. They are also commercially important, being exploited for the production of dyes, drugs, artificial flavouring compounds, and perfumes amongst others (Bruneton, 1999; Heinrich *et al*, 2004). Fig.1 generalises the functions of these compounds in plants.

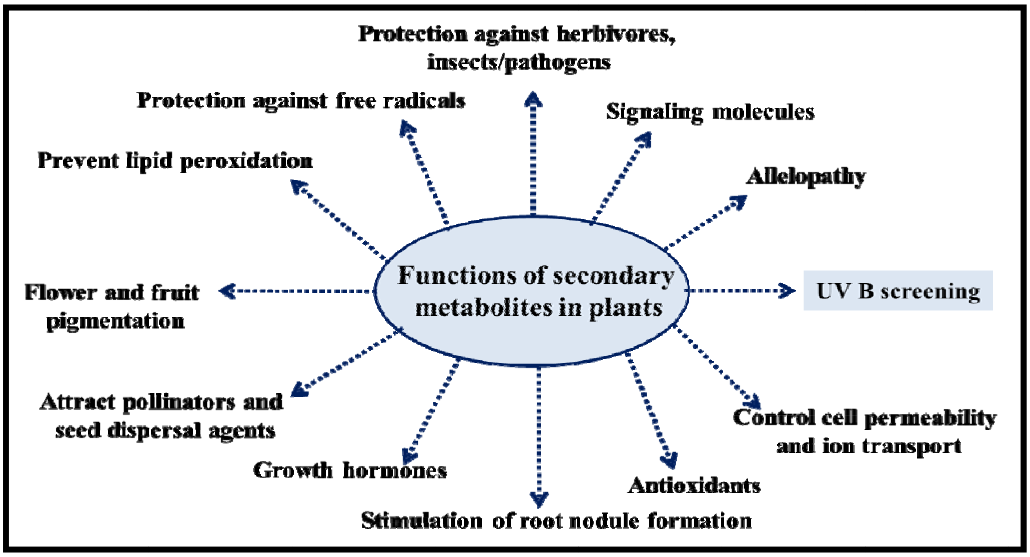

Fig.1. Generalized functions of secondary metabolites in plants

4. Effects of UV-B on Plant Phenolics

The phenylpropanoid pathway, leading to the production various categories of phenolic compounds, is omnipresent in plants. Phenolics comprise more than 10,000 structures known to date; flavonoids comprise the largest group of phenolics with more than 6000 members (Bowsher and Tobin, 2008). Their classification, based on that of Daniel (2006) is outlined in Fig. 2.

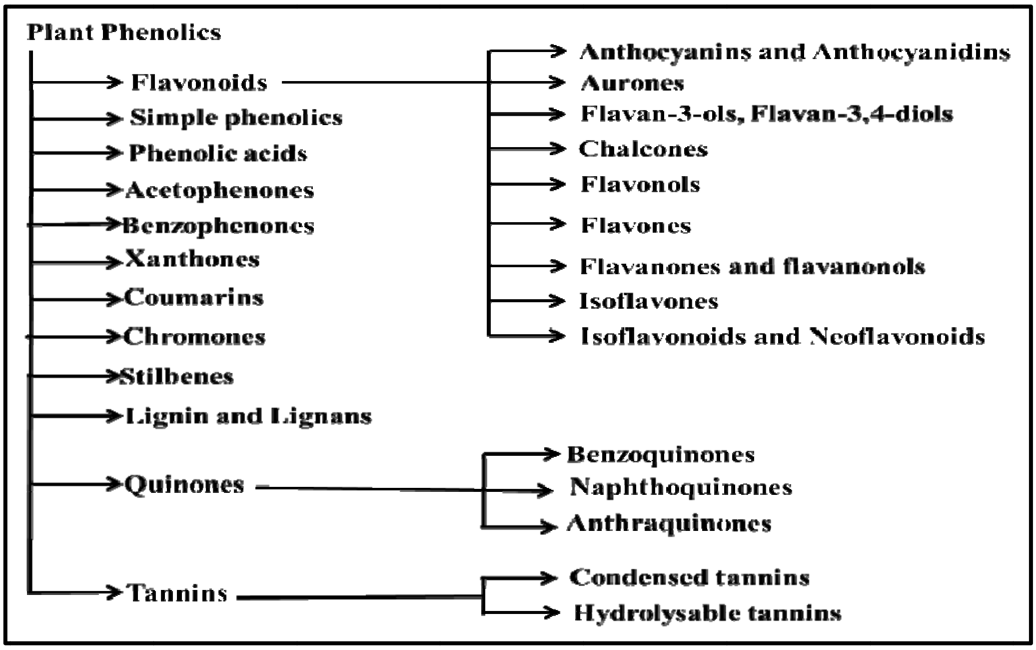

Fig.2. Classification of phenolic compounds synthesized via phenylpropanoid pathway (based on Daniel, 2006)

Both soluble and insoluble forms of plant phenolics absorb in the UV-B range and hence act as effective sunscreen pigments. The former are rapidly inducible upon UV-B exposure while the cell wall bound forms are more passively induced (Lavola *et al*, 2003). Phenolic compounds also act as efficient ROS scavengers (Agati and Tattini, 2010; Fini *et al*, 2011). Some other important functions of plant phenolics include stimulation of root nodule formation, offering disease resistance, regulating auxin transport and cell growth, and functioning as allelopathic agents (Koes *et al*, 1994; Pierpoint, 2000; Chong *et al*, 2009; Kuhn *et al*, 2011). Some important categories of phenolic compounds studied under s-UV-B are given below.

Anthocyanins (sugar conjugates of anthocyanidins) may also form conjugates with hydroxycinnmates and organic acids. They have been known to accumulate under low fluence UV-B in crops such as maize, rice, apple, rose, and *Arabidopsis* (referenced in Guo *et al*, 2008). Anthocyanins are believed to increase the antioxidant potential of plants in order to uphold the balanced physiological status in tissues under UV-B stress. In several medicinal/fruited cultivars, anthocyanin accumulation is induced by light in the UV-B region (280-320nm wavelength range) when applied in combination with solar infrared radiation (Arakawa, 1988).

Flavonols, a category of flavonoids occurring as O-glycosides have been found to increase upon exposure to UV-B. Common examples include myrecetin, quercetin, and kaempferol and their derivatives. Quercetin glycosides and kaempferol 3-rhamnoside enhanced upon UV-B exposure in the leaves of silver birch while myrecetin content remained unchanged (Tegelberg *et al*, 2001). More recently, both quercetin and kaempferol concentrations were found to be increased under elevated UV-B levels in young broccoli plants by Kuhlmann and Müller (2009), mung bean cultivars HUM1 and HUM12 and pea cultivars HUP2 and HUDP15 by Choudhary and Agrawal (2014a, b). It has also been hypothesised that quercetin flavonols are better able to scavenge free radicals than kaempferol flavonols and hence quercetin/ kaempferol ratio is highest in UV-B exposed plants for better protection against oxidative stress (Harborne and Williams, 2000). Moreover, UV-B exclusion studies conducted on strawberries revealed reduced concentrations of flavonols quercetin 3-glucuronide and kaempferol 3-glucoside and also that of anthocyanin cyanidin 3-glucoside (Josuttis *et al*, 2010). Exposure to UV-B causes the accumulation of these compounds in the epidermal layers of exposed plant organs where they act as filters denying excessive light penetration to the internal tissues and organs (Wilson *et al*, 1998). Flavones (closely resembling flavonols) also function in the same vein.

Flavonoids in general were found to be increased in a number of plants upon exposure to elevated UV-B levels, for instance, in leafy salad plant *Gynura bicolor* (Schirrmacher *et al*, 2004), *Vitis vinifera* (Majer and Hideg, 2012), *Raphanus sativus* (Singh *et al*, 2012), *Hordeum vulgare* (Klem *et al*, 2012), andmung bean and pea cultivars (Choudhary and Agrawal, 2014a, b) to cite a few. Flavonoids act as stabilizers and protectors of the lipid phase of the thylakoid membrane and act as quenchers of triplet (excited) state chlorophyll and singlet oxygen generated under oxidative stress (Agrawal and Rathore, 2007). A UV-B exclusion study conducted on some phenolic acids (caffeic acid, *p*-coumaric acid and ferulic acid) in tomato found them to be 20% lower when grown under complete UV-B exclusion (Luthria *et al*, 2006). Coumarins and furanocoumarins absorb strongly in the UV wavebands and increase with enhanced UV B radiation in *Pastinaca sativa* (Zangerl and Berenbaum, 1987).

Postharvest supplementary UV-B application can also increase the concentration of various phenolic compounds. UV-B dose of about 0.5 KJ m^{-2} d^{-1} increased flavonols and phenolic acids (hydroxycinnamic and hydro-xybenzoic acids) in black currant and white asparagus spears (Huyskens-Keil *et al*, 2007). Furthermore, increasing postharvest UV-B dosages enhanced concentrations of quercetin in onion (Higashio *et al*, 2005) and increased anthocyanin levels in peach, apples and strawberry (Marais *et al*, 2001; Kataoka and Beppu, 2004; Higashio *et al*, 2005). In berry fruits, anthocyanins were reported to increase after UV irradiation within a short time (Huyskens-Keil *et al*, 2007), whereas in UV-B treated apples, increased synthesis of flavonols was faster and flavonol accumulation was higher in comparison to anthocyanins (Ban *et al*, 2007; Hagen *et al*, 2007). These findings indicate that flavonols might have a greater impact on antioxidant protection against UV-B. Interestingly, antioxidant activity was highly correlated with the UV-B mediated increase in flavonoid pattern of berry and apple fruits (Hagen *et al*, 2007; Huyskens-Keil *et al*, 2007).

Other end-products of the phenylpropanoid pathway such as lignin are also influenced by UV-B radiation. UV-B causes changes in the lignin content and composition of plants (Rozema *et al*, 1997). Increased epidermal wall thickness due to enhanced lignin deposition was observed by Hilal *et al* (2004) in *Chenopodium quinoa* cotyledons, Yamasaki *et al* (2007) in trichomes of *Cucumis sativus* cotyledons and Tripathi and Agrawal (2013) in *Linum usitatissimum* L. Tannin concentrations were found to be unaffected or negatively affected by UV-B radiation (Kreft *et al*, 2002; Lavola *et al*, 2003) which signifies that plants synthesize only those compounds which are important safeguards against UV-B stress (de la Rosa *et al*, 2001). However, Germ *et al* (2010) reported an increase in tannin content in leaves of *Hypericum perforatum*.

5. Genes and Enzymes of Phenylpropanoid Pathway as Influenced by UV-B

The enzymes and products of the phenylpropanoid pathway (leading to a vast array of phenolic compounds) are the most widely studied under UV-B influence. As reported in the previous section, UV-B has been known to increase the concentration of flavonoids (and its subgroups like anthocyanins, flavonols, chalcones), stilbenes, lignin, and tannins in a number of plant species. Enzymes such as PAL (phenylalanine ammonia lyase, catalysing the transformation of phenylalanine to *trans*-cinnamic acid), CHS (chalcone synthase, which catalyses the first committed step of this pathway utilising malonyl CoA and 4-coumaroyl CoA to produce chalcones), IFS (isoflavone synthase, involved in plant defence and root nodulation), IFR (isoflavone reductase, responsible for phytoalexin biosynthesis involved in plant defence), DFR (dihydroflavonol reductase, first enzyme in the pathway committed to anthocyanin biosynthesis), F3H (flavanone-3-hydroxylase, necessary for the production of both flavonols and anthocyanins), and other enzymes have been studied under UV-B and have been found to be usually up-regulated in plants such as lettuce, *Phaseolus trilobus* (wild gram), *and Ligustrum vulgare* (common privet) (Tomas-Barberan and Espin, 2001; Treutter, 2005; Park *et al*, 2007; Ravindran *et al*, 2010; Agati *et al*, 2011 and references therein). Anthocyanin biosynthetic pathway enzymes have also been reported to be triggered by UV-B radiation in *Arabidopsis* (Fuglevand *et al*, 1996).The elevated levels of transcripts of PAL, DFR, and ANS (anthocyanidin synthase) were accompanied by an increase in the anthocyanin pigments (Guo *et al*, 2008). Ubi *et al* (2006) reported an increased accumulation of anthocyanin pigments in apple fruit skin by inducing the expression of anthocyanin biosynthetic genes, especially chalcone synthase, anthocyanidin synthase, and anthocyanin-3-O-glucosyl trasnferase genes.A series of involved enzymes, such as phenylalanine ammonialyase, cinnamate-4-hydroxylase, p-coumaroyl-CoA ligase and stilbene synthase involved in resveratrol synthesis were shown to be upregulated by UV-B irradiation in grape berries (Li *et al*, 2008).

6. Phenolic Compounds and Benefits for Human Health

Initially, secondary plant metabolites were dismissed as anti-nutritive plant substances in terms of human nutrition. However, the importance of secondary plant metabolites for human nutrition has been reconsidered due to the discovery of their protective potential and health-promoting benefits that range from the stimulation of antioxidative mechanisms to a reduced risk of cancer incidence and cardiovascular disease (Watzl and Leitzmann, 2005). Amongst all plant secondary metabolites, phenylpropanoids are considered to be of immense biological importance because of their antioxidant properties. This property enables them to be utilized as important constituents of human diet from nutritional and health perspective. For instance, polyphenolic antioxidants may help reduce incidence of cancer, cardiovascular and neurodegenerative diseases, prevent DNA damage and may be involved in anti-ageing, preventing age-related disorders (Obrenovich *et al,* 2010). Hollman and Katan (1999) have found that intake of flavonols and flavones were inversely associated with subsequent coronary heart disease in most of the studies they reviewed. The general public has become increasingly aware of and concerned about overall food quality (Schreiner, 2009), therefore an interesting possibility is to exploit UV-B induced metabolic changes in fruit, vegetables and herbs to satisfy consumer demand for natural health-promoting food products. Some of the common categories of phenolic compounds and their health benefits/ medicinal properties are outlined in Table 1.

Table 1. Some important categories of phenolic compounds and their medicinal properties

Phenolic compounds	Medicinal Properties	References
(i) Flavonoids:	Anticancer, anti-viral, anti-allergic, anti-stress, estrogenic antibiotic, antioxidant, antidiarrheal, antiulcer, anti-inflammatory	Sharma 2006, Lu *et al* 2006,Agrawal 2011
a. Anthocyanins and Anthocyanidins	Antioxidant, anti-platelet, chemopreventive, antimicrobial, anticarcinogenic, proapoptotic, neuroprotective, cardioprotective, anti-hepatotoxic, anti-lipolytic, vasodilatory, enhance memory	Hollman and Katan 1999, Scalbert *et al* 2005, Youdim 2002; Lucioli 2012
b. Flavonols	Anti-mutagenic, antioxidant, antimicrobial, anti-carcinogenic, anti-hypertensive, anti-allergic, anti-depressant, anti-diabetic, enzyme-inhibitors, neuroprotective, cardioprotective, chemopreventive,	Bohm 1998, Bruneton 1999 Cai *et al* 2004, Goutam and Dilip 2006
c. Flavones	Anti-tuberculosis, anti-microbial, anti-tumour, antioxidant, anti-carcinogenic, anti-inflammatory, anti-proliferative, anti-angiogenic, anti-estrogenic, improvement of blood circulation	Bohm 1998, Bruneton 1999, Havsteen 2002, Huang *et al*, 2009, Kashani *et al* 2012

d. Flavanones and flavanonols	Antioxidant, antiproliferative, estrogenic, radio-protective, anti-inflammatory, analgesic, anti-hypercholesterolemic, anti-carcinogenic, antimicrobial, hepatoprotective, CNS depressants	Bruneton 1999, Pietta 2000, Tamilselvam *et al* 2013
(ii) Phenolic acids	Anticancer, cardio-protective, anti-ulcer, cytotoxic, antioxidant, antiseptic, antimicrobial, anti-inflammatory, anti-tumour, anti-spasmodic, anti-depressant, treatment of dyspepsia	Dalen 2006, Cai *et al* 2004, Luk *et al* 2007, Surveswaran *et al* 2007
(iii) Coumarins	anthelmintic, anti-asthmatic, anti-coagulant, anti-tumour, anti-viral, anti-inflammatory, anti-oxidant, anti-microbial and enzyme-inhibitory, anti-obesity, anti-mutagenic, digestive,astringent, stomachic, heart tonic, hypoglycaemic, spasmolytic, vasodilators	Daniel 2006, Kontogiorgis *et al* 2007, Borges *et al* 2009
(iv) Stilbenes	Chemoprotective, anticancer, antioxidant, anti-ageing, anti-angiogenesic, neuroprotective, anti-fungal, immune modulation	Shankar *et al* 2007, Zykova *et al* 2008, Zhang and Björn 2009, Kasiotis *et al* 2013
(v) Lignans	Antimicrobial, antioxidant, anti-inflammatory, anti-cancer, antiviral, anti-pyretic, diuretic, analgesic, anti-rheumatic, anti-neoplastic, phytoestrogenic, cathartic, immunosuppressive, hepato-protective, cardio-protective, treatment of osteoporosis, rheumatoid arthritis, gastric and duodenal ulcers	Bernhoft 2010, Nagar *et al* 2011
(vi) Quinones:		
a. Benzoquinones	Antioxidant, anti-inflammatory, anti-cancer, treatment of mitochondrial diseases, prevent atherosclerosis, retinal cell apoptosis	Perez-Sanchez *et al* 2012, Lulli *et al* 2012, Skulachev *et al* 2009
b. Naphthoquinones	Antibiotic, anti-viral, anti-inflammatory, anti-pyretic, anti-proliferative, cytotoxic, anti-allergic, anti-asthmatic	Romanova *et al* 1978, Babula *et al* 2009
c. Anthraquinones	Anti-inflammatory, anti-depressant, antimicrobial, anti-dermatic, anthelmintic, purgative, tonic, treatment of gout, rheumatism, leukaemia, responsible for peristaltic colon movement and water and electrolyte secretion	Duke 1985, Cai *et al* 2006, Huang *et al* 2007
(vii) Tannins :		
a.Condensed tannins	Antioxidant, anti-cancer, anti-HIV, anti-diarrhoea, anti-inflammatory, antibacterial	Gurib-Fakim 2006, Kashani *et al* 2012
b. Hydrolysable tannins	Anti-diarrhoea, antidote in poisoning by heavy metals	Heinrich *et al* 2004, Bernhoft 2010, Kashani *et al* 2012

7. Challenges and Future Perspectives

Certain difficulties might be encountered while inducing secondary metabolite(s) via UV B radiation. UV B alters the concentration of not only the desired compound but the overall secondary metabolite profile (Schreiner *et al*, 2009). Also, some compounds may not necessarily respond favourably to UV B radiation (Schmidt *et al*, 2011). In addition, UV B induced changes in plant secondary metabolite concentration may synergistically or antagonistically affect levels of other primary and secondary metabolites. The bioavailability of the desired compound may also prove to be an issue. Accurate assessment of bioavailability in humans is difficult, expensive, and time-consuming. However, validated cell culture models can also be used to assess bioavailability in a cost-effective and rapid manner (Aherne *et al,* 2009; O'Sullivan *et al,* 2010).

The consumption of secondary metabolites above the toxicity threshold may have potential adverse health consequences. Therefore, studies involving detailed evaluation of these compounds, along with exhaustive dose-response studies need to be performed to better understand the roles of the desired compounds in foods and nutraceuticals of human diet (Son *et al*, 2008). Hence, UV B induced changes in plant metabolome call up meticulous researches in both animal as well as human models.

In the usage of plants for bio-manufacturing purposes, the production and isolation of single secondary plant metabolites in nutraceuticals can be promoted via UV B radiation if a detailed and intricate knowledge of the key regulatory steps of the biosynthetic pathway are known. The dose of the stress can also be optimised to yield the enhanced concentration of the desired secondary metabolite (Schreiner and Huyskens-Keil, 2006; Schreiner *et al*, 2009, 2011). Clearly, the use of UV B radiation to improve the nutritional quality of food products is likely to be a case of 'precision manipulation' whereby UV doses, accumulation dynamics, other environmental parameters, genotype and cell regulatory steps will all need to be considered and regulated simultaneously to achieve the desired results.

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