

Medicinal Plant Active Compounds Produced by UV-B Exposure

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Abstract Ultraviolet (UV) radiation is a part of the sunlight reaching Earth surface. The UV spectrum of solar radiation is by convention divided into three parts: UV-A: 310–400 nm, UV-B: 280–310 nm and UV-C: less than 280 nm. UV-B is the most energetic component reaching Earth surface because the stratospheric ozone layer effectively absorbs completely wavelengths below 290 nm. UV-B is an increasing threat due to increasing UV-B levels on Earth surface as a consequence of depletion of stratospheric O₃. In general, the effects of atmospheric UV-B radiation are negative for biological life. Enhanced levels of UV-B radiation can indeed negatively change plant physiological processes, growth and productivity. However, while studying UV-B effects on medicinal plants, some interesting phenomena have been discovered. For example, basil plants respond positively to UV-B radiation by increasing oil yield (Chang et al. *J Horticult For* 1:27–31, 2009). In other studies medicinal plants show beneficial aspects in term of increase in volatile oil yield and secondary metabolite production (Kumari et al. *Ecotoxicol Environ Safety* 72:2013–2019, 2009c, 2010). Medicinal herbs have great market value in India and worldwide. The medicinal value of plants depends upon phenolics, antioxidants and volatile yield. Therefore further UV-B experiments increasing the levels of these compounds are needed.

Here we review the effect of UV-B exposure on metabolites, volatiles, and antioxidants potential in medicinal plants. This chapter reports: (1) aspects of the global market for medicinal and aromatic plants in India in order to assist the medicinal plant industry to make informed decisions. (2) The biodiversity loss due to wild harvesting of plants, and as an alternative the cultivation strategy of medicinal plants.

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(3) Main medicinal plant species having rich antioxidant potential. (4) Main secondary metabolites of plant origin such as phenylpropanoids, terpenes, alkaloids, and volatile oil, and other important metabolites containing high antioxidant level used in human diet and health. (5) UV-B factors that enhance the quality of medicinal plant by increasing the content of secondary bioactive products. (6) Secondary metabolic pathways involving regulation of key enzymes, chalcone synthase, and phenylalanine ammonia lyase. Understanding of UV-B responses on secondary plant metabolites expand new opportunities for plant enriched in medicinal active compounds.

Keywords Medicinal plants • UV-B • Antioxidants • Secondary metabolites • Phenylpropanoids • Terpenoids • Alkaloids • Essential oil • Health benefits

List of Abbreviations

UV-B	Ultraviolet-B
ROS	Reactive oxygen species
NOx	Nitric oxide
HIV	Human immunodeficiency virus
SARS	Severe acute respiratory syndrome
TIA	Terpenoid indole alkaloids
PAL	Phenylalanine ammonia lyase
C4H	Cinnamate 4-hydroxylase
CHS	Chalcone synthase
DFR	Dihydroflavonol 4-reductase
DXS	1-deoxy-d-xylulose5-phosphate synthase
IPPI	Isopentenyl diphosphate isomerase
GPP	Geranyl diphosphate
FPPS	Farnesyl diphosphate synthase
DAHP	3-deoxy-D-arabino-heptulosonate-7-phosphate
DPPH	Diphenylpicrylhydrazyl

1 Introduction

During the past decade, therapeutic potential of medicinal and aromatic plants with rich contents of secondary bioactive metabolites have received increased attention for scientific investigation. Despite the progress in synthetic drug chemistry, plants still constitute an important source of new products of medicinal value for pharmaceuticals, used commercially either as an antioxidants or nutritional supplements (Zhang and Björn 2009). Among the many medicinal plants routinely used as Ayurvedic medicines in India, some of these plants have been featured in Fig. 1. Many of the herbal

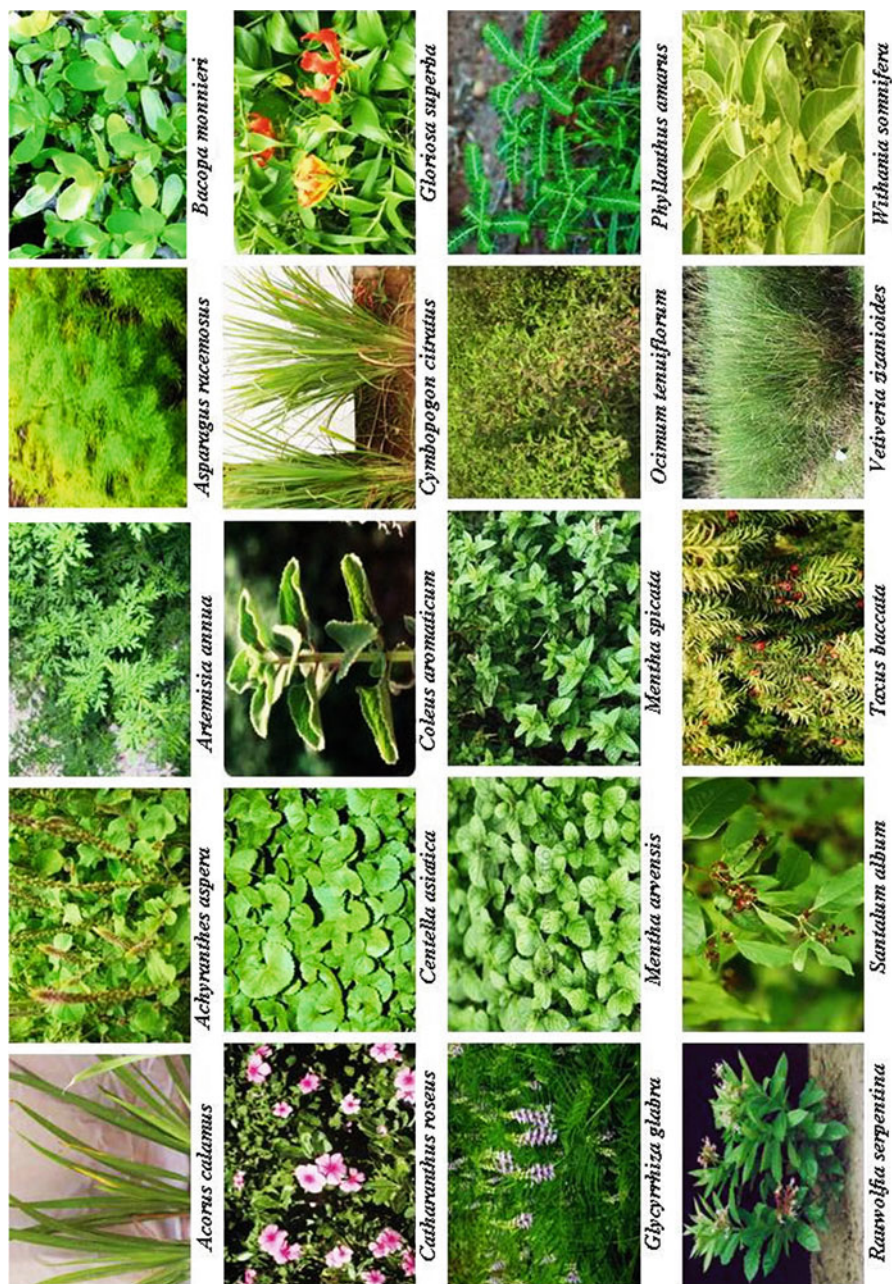


Fig. 1 Some selected Ayurvedic medicinal plants of India

drugs are simple synthetic modifications of these naturally plant derived secondary metabolites. In recent years, increasing attention has been paid by consumers and researchers to the health and nutritional aspects of metabolites such as phenolics, vitamins, minerals and others. Secondary metabolites biosynthesis is a new tool in the generation of novel and expensive natural products. Many of these phytochemicals; phenols, flavonoids, steroids, alkaloids, terpenoids, anthocyanins, glycosylates, β -carotene, ascorbic acid, polyamines, synaptic ester, volatile oil, having high antioxidant potential, be helpful in treatments of several oxidative stress related disorders (Krishnaiah et al. 2007; Kaur and Arora 2009). These antioxidants mitigate the risk of number of chronic and cardiovascular problems and other free radical mediated diseases including neuro degeneration (Nambiar et al. 2010). Finding new natural sources of antioxidant compounds with potential antiradical activity can be useful to future therapy against various stress related health problems.

Increasing awareness of role of antioxidants and various active phyto- constituents in medicinal plants is raising greater impetus for scientists to evaluate and determine how the contents and quality of these natural products and their anti-oxidative potential can be maintained or even improved through different agro -technical processing . In addition, Environmental factor also influence accumulation of key compounds. Ultraviolet-B radiation (280–310 nm) is one factor, expected to modify the chemical composition of plants and induces changes in level of secondary metabolites. Recently, the knowledge about the treatment response of UV-B exposure on different plant metabolites in terms of “health beneficial aspects” is exponentially increasing and has led to novel insights, especially as far as medical, pharmacological and nutritive aspects are concerned (Jansen et al. 2008). Evidently, based on findings by various researchers this novel concept may be presented that, UV-B supplementation might be beneficial for sustainable agriculture, food and nutritional industries for determining the high commercial utilization of these natural medicinal products (Kumari et al. 2009a, c; Kumari and Agrawal 2010; Sun et al. 2010; Eichholz et al. 2011).

Rather than some researches goes on, there is limited understanding of the effect on secondary plant metabolites such as phenolics and volatiles in different medicinal plants, at all. The role and importance of UV-B on induction of phytochemicals in today’s used medicinal plants needed to be explored as it may represent a new practical approach to promote the quality and quantitative yield of metabolic product.

2 Global Trade, Demand and Supply of Medicinal and Aromatic Plants from India

The world health organization has estimated that more than 80% of the world population in developing countries depends primarily on herbal medicines for basic healthcare needs (WHO 2002; Vines 2004). People rely more on natural product derived from shrubs, herbs and trees of great medicinal value as herbal medicine is safe and effective, at low cost with least and/ or no side effects. So on

in present scenario, medicinal and aromatic plants occupy a priming economic position because of the continuous and increased demands of their products at local, national and international markets. Further, there has been ever increasing demand especially from developing country for more and more drug from plant resources.

India is one of the major exporters of crude drugs mainly to six developed countries; USA, Germany, France, Switzerland, U.K. and Japan, who share about major export of total market. According to World Bank study, Global market for the Botanical medicines is estimated as around US \$60, and is projected to reach US\$5 trillion by 2050 (WHO 2003). About 75–80% of the total exports of crude drugs come from India (Shetty 2011). An overview of the global markets for medicinal and aromatic plants from India, supply and international demand of these products may expand information regarding opportunities of the markets for medicinal and aromatic plants in India. This is to assist to make informed decisions on the development of their medicinal plant industry.

3 Commercial Cultivation of Medicinal and Aromatic Plants

The growing demand of plant-based medicines, health products, pharmaceuticals, food supplements, in etc., is putting an unsustainable threatening on forests resulted in increased hazard and extinction of several species, because of overexploitation of wild plant populations. Forests contribute to more than 90% of the medicinal plants used for manufacturing medicines. Large-scale wild harvesting from the forests has caused serious depletion of a number of economically-important species, loss of genetic biodiversity, environmental degradation. According to estimate, more than 4,000 species of medicinal plants are globally threatened, largely due to commercial over-harvesting to meet the demand from pharmaceutical industries (Schippmann et al. 2002). So on, conservation of medicinal plants is needed for a number of reasons. Firstly, they are an important source of natural ingredients used by the manufacturers of modern pharmaceuticals. Second, its tremendous use as botanical dietary supplements in past few decades, leads to continuous erosion of forest and the forest product (Kala et al. 2006). Shifting from wild harvesting to cultivation techniques appeared to be an important alternative strategy to overcome the problem (Uniyal et al. 2000). In cultivation, agro-technological processing can be manipulated in order to achieve desired products, increased yield or stable concentrations of biologically active phytochemicals and reduced toxin level of botanical products (Canter et al. 2005). Cultivation of medicinal and aromatic plants gives scope to optimize yield and achieve a uniform, high quality product at cost of least destruction (Wiersum et al. 2006). As a concluding remark, in this section, we summarized the aspects of biodiversity loss related to wild harvesting of plants and cultivation strategy of medicinal plants from the wild, to be – of better option, to conserve valuable wild medicinal plants.

4 Therapeutic Use of Medicinal Plants as Antioxidants

The use of herbal drugs is widespread and serves as leading research for the development of novel pharmacological agents. A large number of medicinal plant species have already been tested for their potential biological, therapeutic and pharmaceutical activities worldwide (Majhenic et al. 2007; Mata et al. 2007; Wannissorn et al. 2005). Several studies from different countries have confirmed their antioxidants activity in various plants having rich medicinal value (Desmarchelier et al. 1998; Liu and Ng 2000; Soury et al. 2008; Ayoola et al. 2008). Fenglin et al. (2004) have screened the free radical scavenging activity of Chinese medical woody plants showed that most of them are employed for their effects on hemostasis, as anti-inflammatory, antimicrobial or for treatment of dysentery and there medicinal uses may be directly linked to the content in tannins and flavonoids and consequently to their free radical scavenging activities. Zakaria (2007) identified the biochemical compounds such as Flavonoids, triterpenes, saponins and tannins responsible for the observed antioxidant activity in some herbal species; e.g. *Muntingia calabura*; *Bauhinia purpurea*; *Dicranopteris linearis*; *Melastoma malabathricum*; *Corchorus capsularis*. Pourmorad et al. (2006) noticed that greater amount of phenolic compounds relates with higher radical scavenging effects in *Mellilotus officinalis*. In India also, several investigators has been worked at this specific context in assessing the antioxidant capacity of herbal medicine (Chanda and Dave 2009; Kaur et al. 2008; Ali et al. 2008). Prakash et al. (2007) have identified the total phenol, antioxidant and free radical scavenging activities of some Indian medicinal plants, e.g. *Azadirachta indica*, *Cassia fistula*, *Casuarina equisetifolia*, *Indigofera tinctoria*, *Lawsonia inermis* and *Trewia nudiflora*. These plants are having high phenolic content and antioxidant activity. Kshirsagar and Upadhyay (2009) have studied the antioxidative effects of 32 plant species from Tripura, northeastern India and observed that 16 of them e.g. *Mitragyna rotundifolia*, *Schima walichii*, *Syzigium cerasoides* and others showed higher antioxidants potential depends on their dose dependent activity. Jain et al. (2010) have studied on *Alangium salvifolium* and reported that the extract from its roots have interesting potential free radical scavenging activity for treatment of diseases. Patel et al. (2010) worked on antioxidant activity of some selected medicinal plants from western region of India and screened the high radical scavenging activity in the stem of *Kigelia* followed by leaf of *Hibiscus*, *Gemelia* and *Kigelia*. Since the phyto-constituents and volatiles of medicinal herbs have created renewed demand in their use by the public, explorations of health benefits and antioxidant potential of these metabolites in the prevention of oxidative stress problems is needed. This part described the summarized view on antioxidant activity of various medicinal plants. Most of the medicinal plants are rich antioxidants due to its different active ingredients that determine its antioxidant potential.

5 Radical-Scavenging and Antioxidant Potential of Secondary Metabolites

Oxidation process is one of the most important routes for producing free radicals and reactive oxygen species (ROS), in food, drugs and living systems. These reactive species exert can cause substantial biological damage; lipids, proteins and DNA damage, leading to many chronic disorders in humans such as cancer, diabetes, aging, and other degenerative diseases if excess ROS are not eliminated by antioxidant defense system (Halliwell 1994; Petersen et al. 2005). Antioxidants plays major role in reducing such free radical induced tissue injury and in overcoming stress constraints, capable of acting as peroxide decomposers, singlet and triplet oxygen quenchers, enzyme inhibitors and synergists (Edreva et al. 2008). Several phytochemicals; phenolic compounds e.g. coumarins and quinones, nitrogen compounds e.g. alkaloids, terpenoids, carotenoids e.g. beta-carotene, curcumin, ascorbic acid and flavonoids; orientin and vicinin have demonstrated to represents significant antioxidant activity (Rice-Evans et al. 1995; Larson 1988).

5.1 Phenolic Compounds

Last few years, much interest has been attracted to use of natural and synthetic phyto-phenolics as antioxidants, UV screens, anticancer, antiviral, anti-inflammatory, wound healing, and antibacterial agents. Phenolics, belong to the phenylpropanoids are major group of phytocompounds, having more than 10,000 groups of compounds. They found to be derived mainly from phenylalanine and tyrosine. “Phenolics act as multiple defense response as in photo-oxidative pigmentation such as anthocyanins, flavonoids), antioxidation” (Alothman et al. 2009). The combination of antioxidant abilities and scavenging reducing radicals makes the phytophenols ideal substrate for balancing the cell redox status under oxidative stressed condition (Dai and Mumper 2010). Studies showed that the phytophenols can also quickly repair DNA radical anions by an electron transfer reaction (Sperandio et al. 2002).

Among polyphenolic UV-B screening pigments, flavonoids aroused considerable interest because of their long had been shown beneficial effects on human health. They have been reported to have antiviral, anti-allergic, anti-stress and estrogenic activity, mitigating the risk of coronary heart diseases, amazing cardio-protective effects through inhibition of peroxidation of low-density lipoproteins, cholesterol, reduce platelet aggregation, or reduce ischemic damage (Nambiar et al. 2010; Kim et al. 2008). Originally their good effects were thought to be due to their “antioxidative” effect and chelating capacity (Atmani et al. 2009). Some research evidences noticed the anti-tumor promoting activity of flavonoids via mechanisms as kinase inhibition and apoptosis (cell cycle arrested) (Kanadaswami et al. 2005).

Anthocyanins are class of flavonoid compounds, which are widely distributed plant polyphenols. Apart from their physiological roles in plants, anthocyanins regarded as important components in human nutrition (Ross and Kasum 2002) that supported by numerous studies, relating high positive correlation of fruit/vegetable anthocyanin pigment content and increased antioxidant capacities (Stintzing and Carle 2004). Anthocyanin functions in counteracting the negative effect of nitrogen and oxygen reactive species (NO_x), maintaining the redox homeostasis of biological metabolism. All the effects of the anthocyanins listed above can be explained by the antioxidant mechanisms, including hydrogen donation, metal chelation, and protein binding (Kong et al. 2003).

Chlorogenic acid is one of the most important polyphenols in human diet. Like other dietary polyphenols, chlorogenic acid is an antioxidant, produced by large variety of fruits and vegetables, coffee plants in response to environmental stress conditions. Some of the closely related phenolics such as ellagic acid, caffeic acid, and ferulic acid, collectively called as Chlorogenic acid. Potentially beneficial properties to humans are such as antioxidant, hypoglycaemic, antiviral and hepatoprotective (Farah and Donangelo 2006). These are also shown to have chemopreventative activity in a number of animal tumor models (Gonthier et al. 2003).

5.2 Carotenoids

Carotenoids are naturally occurring pigmented compounds produced in many plants and microorganisms. Their main biological function is the protection against oxidative damage in plant defense system. Due to the unsaturated nature of the carotenoids they are subject to changes mainly due to oxidation. The antioxidant properties of carotenoids have been suggested as being the main mechanism by which they afford their beneficial effects on human health. Carotenoids could possibly play an important role as anticarcinogenic drug and in preventing several stress related human disorder such as atherosclerosis, cardiovascular, and other degenerative pathologies such as diabetes, Parkinson's and Alzheimer's diseases (González-Gallego et al. 2007). The carotenoid β -carotene is the primary source of vitamin A in the human diet. Carotenoids may mediate their effects via other mechanisms such as gap junction communication, cell growth regulation, modulating gene expression, immune response and as modulators of carcinogen metabolic pathway via Phase I and II drug metabolizing enzymes (Paiva and Russell 1999).

5.3 Alkaloids

Alkaloids are a diverse group of low-molecular-weight, nitrogen-containing compounds found in about 20% of plant species. Some alkaloids are poisonous, while most are having medicinal value. Furthermore, alkaloids have an important

function in the immune systems of living organisms (Tadeusz 2007). The most medicinally important alkaloids of plant origin includes vinblastine and taxol as an anticancerous product, morphine an analgesics, colchicines; cell division suppressant, and scopolamine as a sedative. Alkaloids interact with DNA or gene coding enzymes, can influence electron chains in metabolism and modulate enzyme activity. Cui et al. (2006) reported the antimicrobial, antimalarial, cytotoxic, and anti human immunodeficiency (HIV) virus activities of the isoquinoline alkaloids and explained that possible chemopreventive antitumor promoters are probably related to their radical scavenging activity against diphenylpicrylhydrazyl (DPPH) radical. β -carboline alkaloids showed strong activity against H_2O_2 -induced oxidative DNA damage, and their hydroxyl radical-scavenging property appears to contribute to their antimutagenic and antigenotoxic effects, observed in yeast and mammalian cells, respectively (Moura et al. 2007).

5.4 Terpenoids

Terpenoids are defined as secondary metabolites with molecular structures containing carbon backbones of isoprene (2-methylbuta- 1, 3-diene) units. These largest classes of plant metabolites include many aromatic substances and essential oils (Nassar et al. 2010). More than 40,000 terpenoids compounds have been identified till with new compounds being discovered every year. Plants terpenoids are used extensively for their aromatic quality. They play major role in traditional herbal remedy, used as anti-bacterial, anti-neoplastic, anti-inflammatory, inhibition of cholesterol synthesis and other pharmacological properties (Paduch et al. 2007; Yamunadevi et al. 2011). Among most of the terpenoids produced by plants, few of these are investigated in depth for pharmaceutical application for example artemisinin and taxol for malaria and cancer treatment (Rai et al. 2011; Yamunadevi et al. 2011). In recent publication, Thoppil and Bishayee (2011) reviewed on the potential role of naturally occurring different terpenoids in the chemoprevention and treatment of liver tumors.

5.5 Phytosterols

Plant steroids, also called phytosterols, are isoprenoid-derived lipids and are integral components of the plant cell. Moreover, phytosterols have important pharmacological activities, including antitumor effects against lung, stomach, ovary and breast cancer (Woyengo et al. 2009). Phytosterols limit absorption of cholesterol from fat matrices into the human intestinal tract, decreases the incidence of cardiovascular diseases (Sanclemente et al. 2009). Phytosterols exerts anti-atherosclerotic, anti-inflammatory and anti-oxidative activities.

5.6 Polyamines

Polyamines; putrescine, spermidine and spermine are a group of phytohormone-like aliphatic amine natural compounds with aliphatic nitrogen structure. Polyamines are small ubiquitous polycations, can modulates the function of important biomolecules under stress. These are modulator of stress regulated gene expression and exhibit antioxidants property (Kuznetsov and Shevyakova 2007).

5.7 Glucosinolates

Glucosinolates are defense-related nitrogen- and sulphur-containing plant secondary metabolites, present mainly in species of Cruciferae family. Increase in these aliphatic and indolyl glucosinolates, potentially have important benefits for human health due to their anti-inflammatory and anti-tumorigenic properties (Gomes et al. 2008; Kuhlmann and Muller 2009).

5.8 Essential Oil

Essential oils of aromatic plants have attracted a great deal of interest due to their potential as a source of natural antioxidants and biologically active compounds (Bozin et al. 2006; Tepe et al. 2007; Wannissorn et al. 2005). These active oil gained attention of researchers for its multiple uses in phyto-therapeutics such anti-inflammatory, antitumor, anti-hyperglycemic, anticarcinogenic, and as antioxidants, (Eichholz et al. 2011). For treating intestinal and gastric problems, peppermint oil, coriander oil, basil oil are used, lavender, eucalyptus and chamomile oils for insomnia patients, muscles pain and aches (Wei and Shibamoto 2007), lemon grass oil for treating relief in stress problems, calamus oil for improving intelligence power in children (Kumari et al. 2009a, c).

In brief, this section of review, described the different major group of secondary metabolites of plant origin such as phenylpropanoids, terpenes, alkaloids, volatile oil as well as other important metabolites, containing high antioxidants level that being used in human diet as nutrition supplement as well as important ingredients of several medicinal products related to human health problem.

6 Needs of UV-B Research on Medicinal Compounds

The continuous increasing demand of the global market for aromatic and medicinal plants led to the development of experimental cultivations where environmental factors are of much concern which can improve the quality of products of the studied

plants in relation to their commercial value. In this prospective, UV-B researches on medicinal plants have possessed a great deal of attention for researchers and pharmaceuticals, as they show the positive involvement of UV-B on quality and yield of desired herbal products by inducing volatiles production and compounds of interest of secondary metabolism; phenolics, flavonoids. It may be due to their special consequence on biosynthetic processes as they play a variety of ecological roles. They are having potency to enhance the level of terpenoids, phenylpropanoids, and natural antioxidants (Kumari and Agrawal 2010).

7 Consequences of UV-B Stress: Phytochemical Induction

Application of abiotic stress such as moderate UV-B treatment can induce distinct changes in the plant's secondary metabolism. UV-B induction of different secondary metabolites is represented in Fig. 2. Ultraviolet supplementation has been proposed to increase levels in tocopherol (Higashio et al. 2007), ascorbic acid and flavonoids in some medicinal and aromatic plants (Kumari and Agrawal 2010). Hagen et al. (2007) have evaluated the effects of postharvest UV-B irradiation with visible light and reported the increased value on phenolic contents and evaluated

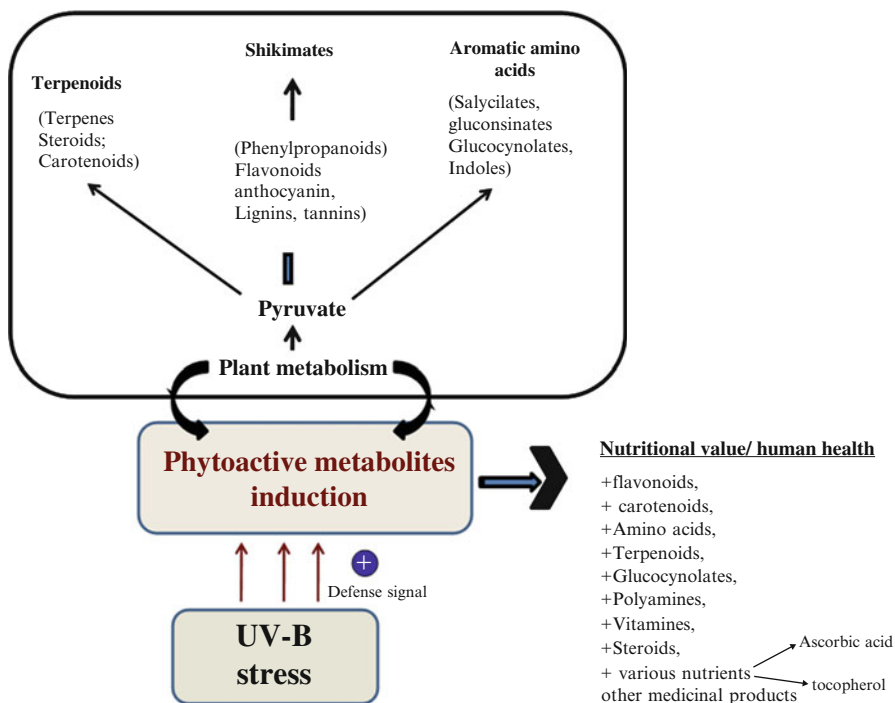


Fig. 2 UV-B induction of different metabolites in plants

content of anthocyanins, quercetin glycosides, chlorogenic acid and ascorbic acid including oxygen radical antioxidant capacity assay in apple fruit upon UV-B irradiation. UV-B treatment affects the important bioactive products in various medicinal plants as documented in Table 1.

UV-B study on secondary metabolites production is mostly centered on UV-B screening “phenolics” compounds. These phytochemicals have been positively linked to several health-promoting properties such as anticarcinogenic and antioxidative characteristics (Holst and Williamson 2004; Schreiner et al. 2009). Phenolics mitigate the effects of oxidative stress by mediating the redox status (Kumari et al. 2009c). Studies reported an increase of phenolic compounds and corresponding antioxidant activity, as in sweet flag (Kumari et al. 2009c), blueberries (Eichholz et al. 2011) etc. Phenolics can act as UV-protectors e.g. because of their absorption of light between 270 and 290 nm. UV-B research on rosmarinic acid, a bioactive compounds of medicinal plant *Rosmarinus officinalis* (Rosemary plants) showed higher yield of rosmarinic acid, when plants subjected to UV-B exposure (Luis et al. 2007). Rosmarinic acid a naturally-occurring and potent phenolic compound antioxidant plays a role in modulating inflammatory diseases including allergies, asthma and atherosclerosis and anti-inflammatory properties.

Flavonoids are the major one UV-B-regulated phenylpropanoid derivatives, rapidly induced by UV-B exposure. Flavonoids stabilize and protect the lipid phase of the thylakoid membrane, and are quenchers of the excited triplet state of chlorophyll and singlet oxygen generated under excessive stress (Agrawal and Rathore 2007). UV-B response on its biosynthesis and regulation have been very thoroughly explored. Two groups of genes are required for flavonoids biosynthesis: structural genes that encode the enzymes that directly participate in flavonoid biosynthesis, and transcription factors that regulate the expression of the structural genes and the accumulation of flavonoids. UV-B radiation stimulates the response of regulatory key enzyme “Phenylalanine ammonia lyase” that’s an important enzyme of flavonoid biosynthesis pathway and transcriptionally induced by UV-treatment (Ravindran et al. 2010).

Some researches noticed the response of UV-B on glucosinolate metabolism, as genes related to the biosynthesis of flavonoids, glucosinolates and terpenoids metabolism were differently expressed after UV-B radiation (Hectors et al. 2007; Wang et al. 2011). Flavonoid and glucosinolate induction depend partly on the same signaling pathways, which involve jasmonic acid (Mackerness and Thomas 1999; Textor and Gershenzon 2009). UV-B application increased the aromatic glucosinolate glucotropaeolin concentration up to sixfold in comparison to the control plants in case study on short-term and moderate UV-B radiation effects on a herbal medicinal plant nasturtium (*Tropaeolum majus*) (Schreiner et al. 2009). Wang et al. (2011) investigated the contents of glucosinolates and the expression of related genes in response to enhanced UV-B radiation and reported that when *Arabidopsis* leaves were irradiated by acute UV-B ($1.55 \text{ W}\cdot\text{m}^{-2}$) for a short time (1 h), it induced the production of glucosinolates, however over exposure (12 h) inhibited the expression of glucosinolate biosynthetic genes and glucosinolate contents decreased.

Table 1 Effect of Ultraviolet-B (UV-B) radiation on secondary metabolites in some plants showing exemplified compounds and its medicinal values

Plant name	Medicinal property	Active ingredients	UV-B dose	UV-B induced	References
<i>Acorus calamus</i> L. Family: Acoraceae	antispasmodic, carminative, anthelminthic, Hypotensive, depressant	β -asarone linalool aristolene, aristolene caryophyllene carvacrol, phenolics	+1.8 kJ m ⁻² d ⁻¹	Decrease in β -asarone percentage No change in linalool Increase in aristolene, p-cymene caryophyllene oxide, carvacrol Increased after UV-B exposure	Kumari et al. (2009c)
<i>Artemisia annua</i> L. Family: Asteraceae	antimalarial, anti-tumor, anti-cancerous	artemisinin	+4.2 kJ m ⁻² d ⁻¹	Increased by 10.5% under UV-B treatment	Rai et al. (2011)
<i>Camellia sinensis</i> L. Family: Theaceae	cardioprotective, chemoprotective, Anti allergic	Tea catechins		Elevated epigallocatechin gallate level in tea leaf by artificial supplementation of UV-B	Zheng et al. (2008)
<i>Catharanthus roseus</i> Family: Apocynaceae	Anti cancerous, Anti-diabetic	Strictosidine, Serpentine, Tabersonine, Catharanthine, Vindoline, Vinblastine	28×10^{-5} kJ/cm ²	Increased respectively by 161%, 8-14% 21-79% 8-14% 8-14% 8-14%	Ouwerkerk et al. (1999)
<i>Catharanthus roseus</i> L. Family: Apocynaceae	***	Catharanthine, vindoline	1.26 μ W/cm ²	Threefold and 12-fold increase respectively, on treatment with 5-min UV-B irradiation	Ramani and Jayabaskaran (2008)
<i>Catharanthus roseus</i> L. Family: Apocynaceae	***	lochnericine serpentine, ajmalicine rhammericine	-	Significant increases after 20 min UV-B exposure Decrease in rhammericine	Binder et al. (2009)

(continued)

Table 1 (continued)

Plant name	Medicinal property	Active ingredients	UV-B dose	UV-B induced	References
<i>Cymbopogon citratus</i> (D.C.) Stapf Family: Poaceae	Anti-depressant, Anti-inflammatory, Antipyretic	Z-citral (terpenoids)	+1.8 kJ m ⁻² d ⁻¹	Up to twofold increase at UV-B exposure	Kumari et al. (2009a, b, c)
<i>Genista Tinctoria</i> L. Family: Fabaceae	hypoglycemic, antiinflammatory antitumor, spasmolytic antioxidant, estrogenic	Isoflavonols: genistin, genistein, daidzein, Biochanin-A	–	isoflavonols formed at higher levels after UV irradiation	Tumova and Tuma (2011)
<i>Ginkgo biloba</i> L. Family: Ginkgoaceae	antimicrobial, neuropro- tector, anti-mutational, and anticancer activity	flavonoids Specific: quercetin, kaempferol isorhamnetin glycosides	82.9 μW's·cm ⁻²	Increased up to 57.2% trends of UV-B induction in quercetin, kaempferol, and isorhamnetin glycosides	Sun et al. (2010)
<i>Glycyrrhiza Uralensis</i> L. Family: Fabaceae	Anti-tumor property	Glycyrrhizin	1.13 W/cm2	UV-B stress stimulates glycyrrhizin concentration	Afreen et al. (2005)
<i>Hypericum perforatum</i> L. Family: Clusiaceae	antidepressive properties	Flavonoids, tannins and hypericin	sUV-B	Increase in level of flavonoids, tannins at supplemental UV-B dose	Germ et al. (2010)
<i>Mentha spicata</i> L. I & II chemotype Family: Lamiaceae	***	Chem: I Piperitone Chem: II: limonene, Carvone, dehydrocarvone	sUV-B simulating 15% ozone depletion	No effect of UV-B on qualitative composition of component in both chemotype	Karousou et al. (1998)
<i>Mentha piperita</i> L. Family: Lamiaceae	Carminative, decongestant Expectorant, relaxing effect on skin	Menthone menthol	0.6 W m ⁻²	Improve oil quality in terms of enhanced rate of menthone to menthol conversion	Behn et al. (2010)

<i>Ocimum basilicum</i> Family: Lamiaceae	Antioxidant, anticancer, anti-microbe	Linalool, β ocimene methyl-eugenol, Eugenol,	UV-B enhancing effect on these phenylpropanoids and terpenoids about fourfold increase in eugenol	Johnson et al. (1999)
<i>Ocimum basilicum</i> L. Family: Lamiaceae	***	1,8-cineole germacrene linalool eugenol	41% and 71.4% increment approx. 3 times at UV-B	Nitz and Schnitzler (2004)
<i>Ocimum basilicum</i> L. Family: Lamiaceae	Antioxidant, anticancer, anti-microbe	1, 8-cineole, Linalool, eugenol.	Significant increase in level of these constituents at UV-B exposure	Chang et al. (2009)
<i>Perilla frutescens</i> L. Family: Lamiaceae	anti-inflammatory, anti-pyretic	perillaldehyde limonene	UV-B suppressed anthocya- nin production, No effect on active components	Nishimura et al. (2008)
<i>Rosmarinus officinalis</i> L. Family: Lamiaceae	Antioxidant, anti-bacte- rial property	Rosmarinic and carnosic acids	Both UV-B radiation treatments increased the concentrations of caffeic, carsonic, rosmarinic acid	Luis et al. (2007)
<i>Taxus chinensis</i> L. Family: Taxaceae	antitumor agent	Taxol	Increased taxol content at supplemental UV-B treatment	Zu et al. (2010)
<i>Tropaeolum majus</i> Family: Tropaeolaceae	Anti-microbial effect	Glucotropaeolin, Phenolic	UV-B application increased the glucotropaeolin concentration up to sixfold in compare to control	Schreiner et al. (2009)
<i>Vaccinium corymbosum</i> Family: Ericaceae	Antioxidant, Anti- micro- bial, anticarcinogen	Total phenolics C6-aldehydes: terpenes, ketones	Increased at UV-B exposure UV-B exposure resulted in an increase in phenolic compounds, Increased aldehydes	Eichholz et al. (2011)

***Represent as descript above; C represents: control, UV-B ultraviolet-B, PAR photosynthetic active radiation

Scientific interest in UV-B research on anthocyanin pigments have been well documented because of their possible health benefits as dietary antioxidants. Anthocyanins, a class of flavonoids is believed to increase the antioxidant potential of plants in order to uphold the balanced physiological status in tissues under UV-B stressed factor. The elevated levels of the transcripts of *Pal*, *Dfr* and *Ans* were accompanied by an increase in the anthocyanin pigments (Guo et al. 2008). In several medicinal/fruited cultivars, anthocyanin accumulation is induced by light in the UV-B region (wavelengths from 280 to 320 nm) when applied in combination with solar infrared radiation (Arakawa 1988). Ubi et al. (2006) reported the increased accumulation of anthocyanin pigments in apple fruit skin by inducing the expression of the anthocyanin biosynthetic genes, especially chalcone synthase, anthocyanidin synthase and anthocyanin –3-O-glucosyl transferase genes.

“Coumarins and furocoumarins have been of particular interest because they are induced by UV radiation”, Psoralens is a naturally occurring furocoumarins absorb strongly within the ultraviolet range (200–320 nm) band. Their photosensitizing property makes them clinically effective in treatment of various dermatological ailments in human being, as vitiligo, leucoderma, leprosy and psoriasis, inducing re-pigmentation (melanocytes formation). Psoralens are reported to be influenced by changes in the UV-B environment in *Abelmoschus esculentus* (Kumari et al. 2009b). Coumarins and furanocoumarins also absorb strongly in the UV wave bands and increase with enhanced UV-B radiation in *Pastinaca sativa* (Zangerl and Berenbaum 1987).

UV-B promotion of terpenoids observes particularly in members of the Lamiaceae family (Johnson et al. 1999; Karousou et al. 1998; Maffei and Scannerini 2000; Behn et al. 2010). A study on Rosemary plant, reported UV-B radiation effect on diterpenes carnosic acid and carnosol (Luis et al. 2007). Johnson et al. (1999) reported the accumulation of terpenoid compounds at seedlings stage (five leaf growth) in basil leaves. Glycyrrhizic acid, a triterpenoid saponin, were found to be increased at optimum UV treatment while with exposure to high UV doses resulting in decreased glycyrrhizin accumulation (Afreen et al. 2005). Glycyrrhizin is major bioactive components of *Glycyrrhiza uralensis* (liquorice) having anti-tumor effect and inhibition of carcinogenicity by the activation of hepatotoxic metabolites (Chan et al. 2003), high activity in inhibiting replication of human immunodeficiency virus (HIV-1) and severe acute respiratory syndrome (SARS) -associated virus (Afreen et al. 2005), and exhibits a number of other pharmacological effects (Zhang and Ye 2009).

In *Catharanthus roseus*, terpenoid indole alkaloids produced in as part of its secondary metabolism. This is supported by the observations that UV light induces the formation of dimeric terpenoid indole alkaloids in *C. roseus* leaves (Hirata et al. 1993; Ouwerkerk et al. 1999). Ramani and Chelliah (2007) reported the significant roles of UV-B induced signaling pathway on transcription of terpenoid indole alkaloids biosynthetic genes encoding tryptophan decarboxylase (*Tdc*) and strictosidine synthase (*Str*) expression leading to increased production of catharanthine in *Catharanthus roseus* cell cultures. An anti-inflammatory monoterpene- indole alkaloid brachycerine in plants of *Psychotria brachyceras* (Rubiaceae) induced almost doubled by UV-B radiation (Gregianini et al. 2003). In study on *Taxus chinensis*, variety *mairiei*, Zu et al. (2010) found the increased content of a alkaloid “taxol” in plants exposed to increased UV-B radiation. Taxol could significantly decrease the

concentration of free radicals generated by the classical fenton reaction and exists as an important anti-oxidant substance. UV induction of alkaloid biosynthesis may be useful for pharmaceutical purpose.

Polyamines may play role in protecting plants against UV-B stress (Kramer et al. 1991). Polyamine acts as stress messengers in plant responses to stress signals (Gill and Tuteja 2010). Polyamines protect against radiation-induced oxidative stress (Deutsch et al. 2005). It plays main role in regulating structure and function of photosynthetic apparatus, in avoiding cellular damage of lipids, proteins and DNA of plants under UV-B stress (Sung et al. 2008; Agrawal et al. 2009).

From the nutritional point of view, UV-B irradiation has even been beneficial in terms of increasing the content of potentially health-promoting stilbene “resveratrol”. Resveratrol (3,5,4'-trihydroxy-trans-stilbene) is produced by certain plants as a defense mechanism. The biological activity of resveratrol as an anticarcinogenic and an antioxidant has been reported in grapes (Jang et al. 1997). A series of involved enzymes, such as phenylalanine ammonia-lyase, cinnamate 4-hydroxylase, p-coumaroyl-CoA ligase and stilbene synthase involved in the resveratrol synthesis that shown to be up-regulated by UV-B irradiation (Li et al. 2008).

In recent years some studies have been carried out concerning the impact of enhanced UV-B radiation on hypericin concentrations and reporting that concentrations of this bioactive substance can be altered by UV-B (Germ et al. 2010). Hypericin is a component of the inducible plant defense response of *Hypericum perforatum* against fungal pathogens (Cirak et al. 2005).

Concluding remark of this part; UV-B factors enhance the quality of medicinal plant via enhancing content of secondary bioactive products in turms of induction of phenolics, flavonoids and other secondary products,

8 UV-B Induction of Essential Oil Yield in Medicinal and Aromatic Plants

The commercial value of an aromatic and medicinal plant could be reflected by the yield and composition of their essential oils. An essential oil is a concentrated, hydrophobic liquid containing volatile aroma compounds having characteristic fragrances in some plants. In several recent and earlier reports on medicinal plants, UV-B radiation is reported to be beneficial in improving the quality of various aromatic plants, showing it's positive role in volatile production as well as inducing changes in chemical composition of its essential oil. An aggregate accent of documented works done so far on the impact of UV-B radiation on volatile oil yield and its qualitative composition in some medicinal plants are shown in Table 2. The contribution of UV-B radiation to stimulation of volatile production and changes in active constituents composition has been examined experimentally by various other researchers as reported in *Ocimum basilicum* (Johnson et al. 1999; Nitz and Schnitzler 2004; Chang et al. 2009), *Mentha spicata* (Karousou et al. 1998), *Mentha piperita* (Maffei and Scannerini 2000); *Glycyrrhiza uralensis* (Afreen et al. 2005). Dolzhenko et al. (2010) reported in study on peppermint that UV-B radiation prompted the higher content of

Table 2 Ultraviolet-B (UV-B) induced response on volatile oil yield and qualitative and quantitative change in essential oil constituents in various medicinal plants from different countries

Medicinal plants	UV-B ($\text{kJm}^{-2} \text{d}^{-1}$)	Photosynthetic active radiation ($\mu\text{mol phot. m}^{-2} \text{sec}^{-1}$)	Experimental condition	Supplemental UV-B induced response	Reference	Country
<i>Acorus calamus</i> L.	Control (ambient) sUV-B (+1.8)	1,100–1,200	Field condition	Increase in essential oil yield by 35% Significant variation in qualitative composition of oil decrease in β -asarone (8.5%), linalool and germacrene-D. Increase in aristolene (47.6%), caryophyllene oxide (66.7%), p-cymene and carvacrool (up to detectable limit) and other component	Kumari et al. (2009c)	India
<i>Cymbopogon citratus</i> L.	Control (ambient) sUV-B (+1.8)	1,100–1,200	Field condition	Essential oil yield increased by 25.7% by treatment of sUV-B. Major compounds of <i>C. citratus</i> oil: Z-citral; increased more than doubled after treatments	Kumari et al. (2009a)	India
<i>Mentha spicata</i> L.	Control (ambient) sUV-B (15% ozone depletion)	Near Ambient	Field condition	UV-B stimulated oil production in chem. I. No change in qualitative composition of oil.	Karousou et al. (1998)	Greece
Chemotype I and II	Control (–UV-B) UV-B	–	Green house	Slight variation in quantitative composition in chem I. Increase in essential oil production Variation in qualitative composition no quantitative change in oil constituents	Maffei and Scannerrini (2000)	Italy

<i>Mentha piperita</i> L.	Control (-UV-B) UV-B (0.6 W m ⁻²)	550 and 1,150	Growth chamber	At high PAR level, Increase in essential oil yield at UV-B Improved oil quality in terms of an enhanced menthone to menthol conversion	Behn et al. (2010)	Germany
<i>Ocimum basilicum</i> L.	Control (-UV-B), UV-B	Ambient day light	Green house	At early stage, no change in volatile yield In five leaf stage of plant: fourfold enhancing effect of UV-B on total volatile content Increase in phenylpropanoids and terpenoids	Johnson et al. (1999)	China
<i>Ocimum basilicum</i> L.	Control (-UV-B), UV-B normal dose	-	Green house	High increase in eugenol (5 times). Increase in essential oil yield (approx >2 times) non-significant variation in qualitative or quantitative composition of volatiles constituents. No change in number of oil glands Expansion and fulfilling of peltate oil sacs, increased aroma due to bursting of oil sacs after sUV-B exposure	Ioannidis et al. (2002)	China
<i>Ocimum basilicum</i> L.	Control (-UV-B), PAR variant, UV-B variant	-	Green house	Increase in essential oil level: (16% in PAR; more then 50% in sUV-B). sUV-B induced changes in oil constituents: Increase in 1,8-cineole (41%), germacrene (71.4%), linalool and eugenol (approx. 3 times) decrease in methyleugenol Increase in phenolics	Nitz and Schnitzler (2004)	Germany
<i>Ocimum basilicum</i> L.	Control (ambient) UV-B (+1.8)	Ambient day light	Field condition	Increased turgidity of oil glands increase in essential oil yield by 42% significant increase in β -caryophyllene, germacrene-D, ethyl linoleolate, β - elemene , camphenol	Kumari and Agrawal (2010)	India

sUV-B supplemental UV-B above ambient, -UV-B UV-B excluded, - information not available

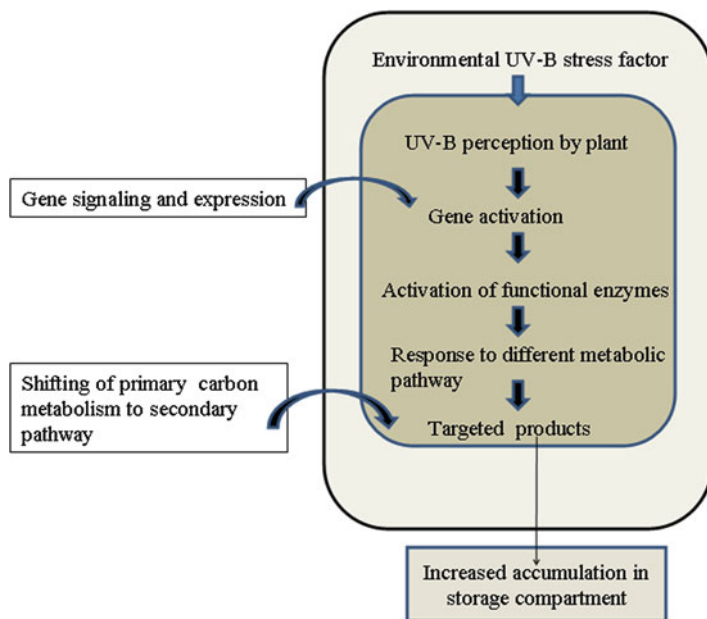


Fig. 3 UV-B stress response on plant metabolism; abiotic stress (e.g., from UV-B radiation) – initiates signal cascades that trigger defense-related genes transcription. Resulting metabolic shifting to secondary metabolism lead to generates higher secondary products as adaptive responses

menthol and phenolic compounds as the modulation of expression of some specific genes involved in essential oil biogenesis (which show menthol production) was usually up-regulated by UV-B irradiation. Moderate and low dose UV-B supplementation are reported to increased the essential oil yield in a important Indian medicinal plant *Acorus calamus* and shown to improve it's health value by reducing the content of potentially toxic constituents β -asarone (Kumari et al. 2009c). Another study on *Cymbopogon citratus* also shown enhancement in it,s medicinal benefits by procuring the higher content of z-citral (a major product) in essential oil as well as enhancing it's yield (Kumari et al. 2009a). Ioannidis et al. (2002) reported the requirement of UV-B for normal development of oil glands in basil leaves.

Concluding remark; UV-B promotes volatile yield as well as induced changes in it's composition, that might proves to useful for enhancing the quality of medical products.

9 UV-B Regulation of Secondary Metabolic Pathways

Plant secondary metabolites are important determinants of plant stress responses (Jansen et al. 2008) (Fig. 3). UV-B radiation is linked to CO_2 assimilation rate to which the carbon skeleton is diverted from the primary metabolism to the secondary

one (Kasige and Takashi 2009). Therefore, UV-B regulation of carbohydrate assimilation and secondary metabolism must be metabolic linked (Interdonato et al. 2011). Most of the stress inducible enzymes such as glutathione-S transferase and phenylalanine ammonium lyase play an important role in triggering secondary metabolites synthesis. Phenylalanine ammonium lyase along with chalcone synthase and other enzyme involve in allocating significant amount of carbon from phenyl alanine into the biosynthesis of several important secondary metabolites (Singh et al. 2009). Plant cytochromes P450s; cytochrome p450 family proteins and p450 monooxygenase involved in catalyzing the metabolic reactions of primary and secondary pathways to produce the biochemical products such as phenylpropanoids, alkaloids, terpenoids, lipids, cyanogenic glycosides, and glucosinolates (Agrawal et al. 2009). However, the exact molecular basis of UV-B signaling cascades leading to increased production of secondary metabolites of plant cell is largely unknown.

These major routes for the production of secondary metabolites in plants are: (1) shikimate pathway for phenylpropanoid compounds; flavonoids and anthocyanins and isoprenoid route of (2) terpenoids and (3) alkaloids biosynthetic pathway. The present literature describe with emphasis on the role of UV-B on these metabolic pathway.

9.1 Shikimate Pathway

Many of plant-derived phenylpropanoids such as flavonoids, isoflavonoids, anthocyanins, coumarines, and lignans are secondary products of shikimate metabolism (Korkina 2007). Expression levels of several genes encoding key enzymes of secondary biosynthetic pathway are being elevated in a coordinated trend at UV-B and other environmental stress signals (Long and Jenkins 1998). Figure 4 showed the diagrammatic representation of different metabolic steps involves in shikimate pathway of phenylpropanoids biosynthesis and it's regulation in response to UV-B radiation. The first enzyme of the shikimate pathway "3-deoxy-D4 arabinoheptulosonate-7-phosphate synthase" (DAHP synthase) that catalyzes the condensation of phosphoenolpyruvate and erythrose-4-phosphate to yield 3-deoxy-D-arabino-heptulosonate-7-phosphate (DAHP) is reportedly induced by UV-B irradiation (Ramani et al. 2010). It proposed that selective transcription of phenylalanine ammonia lyase, chalcone synthase, cinnamate 4-hydroxylase and 4-coumarate: coenzyme A ligase genes, coding functional enzymatic variants, may control the synthesis of phenylpropanoid products also being induced by UV-B stress factor.

9.2 Isoprenoids Pathway

The stimulation of terpene biosynthesis by oxidative stress is well known (Beaulieu 2007). The biosynthesis of terpenes starts with isopreneoid unit with precursors of isopentenyl and dimethylallyl diphosphate. Activation of two independent pathway

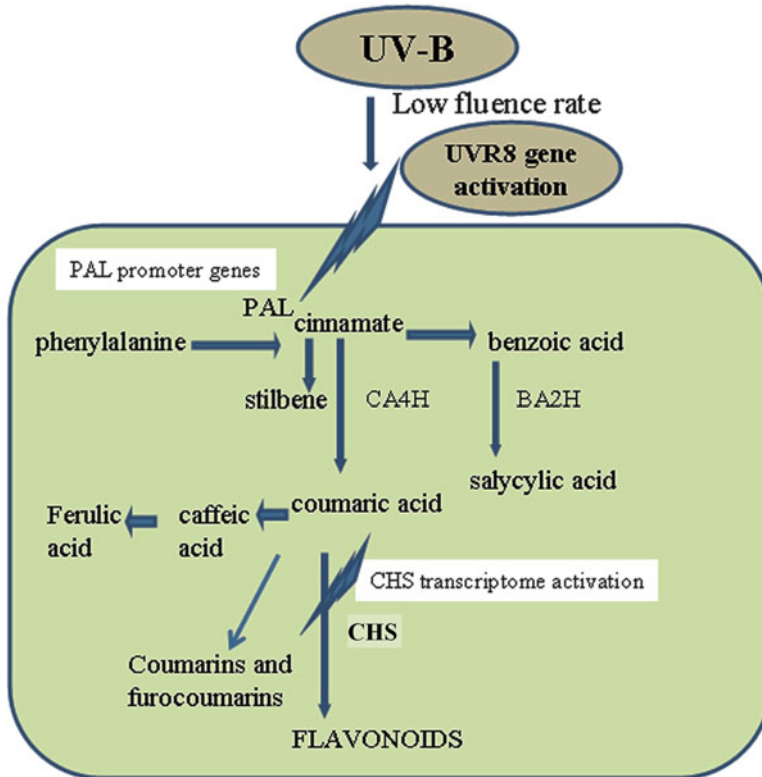


Fig. 4 Schematic representation of UV-B regulation of phenylpropanoids pathway of flavonoid biosynthesis. UV-B stress interferes with metabolic processes (particularly enzyme activity). UVR8 controls multiple gene encoding the principle enzymes of flavonoid biosynthesis. It acts primarily on phenylalanine ammonia lyase (PAL) and chalcone synthase (CHS); key enzymes of flavonoids biosynthetic metabolism

cytosolic acetyl mevalonate, that provides precursor for sesquiterpene and sterols and/or plastidial 1-desoxy-D-xylose-5-phosphate/methyl D-erythritol phosphate for isopentenyl and dimethylallyl diphosphate precursors (Hampel et al. 2005). In a recent publication on grapevine leaves, Gil et al. (2012) suggest that UV-B modulates the metabolism of terpenes leading to specific responses according to fluence rate of UV-B. Relatively low UV-B irradiation induces the de novo synthesis of enzymes of terpene cytosolic mevalonic acid pathway leading to production of terpenes, triterpenes and sterols, while high UV-B irradiance promoted the production of plastidic diterpenes via the methylerythritol phosphate pathway. The effect of increased UV-B irradiation on the expression of genes involved in early steps of terpenoid biosynthesis was reported in peppermint oil by Dolzhenko et al. (2010). “They observed that UV-B irradiation increased the content of some monoterpenes e.g. methol) and sesquiterpenes” e.g. β -caryophyllene and germacrene-D which correlates with induced up-regulation of genes involved such as Dxs, Ippi, Gpps,

and Fpps. Alkaloid biosynthesis in plants is also tightly controlled in response to UV-B stress. Tryptophan decarboxylase, a key enzyme in biosynthesis of the precursor tryptamine needed for monoterpene indole alkaloid production, can be strongly induced by UV-B light at the level of transcription (Ouwkerk et al. 1999).

At all, basic concept behind the activation of combitorial secondary metabolic pathways is due to genetic up regulation of specific key enzymes; chalcone synthase, phenylalanine ammonia lyase. Plant precursors from their own primary and secondary metabolism are metabolized to the desired secondary product due to the up-regulation/ expression of specific/ desired genes in response to UV-B irradiation.

10 Applicability of UV-B on Metabolites Enrichments: Future Perspectives

The valuable pharmacological properties of phytochemicals limited with their low level of production by natural sources. Active researches into novel strategy implied for promoting metabolites production, will definitely be of great importance in present and future in terms of their commercial value. Additional knowledge on specific effect of light quality on metabolites induction will help us in designing the greenhouse light environment to obtain plants with enhanced phytochemical concentrations. The approaches discussed above –health value of various metabolites, UV-B induction of these phytochemicals, secondary biosynthetic pathway, and the UV-B induction of regulatory genes – are likely to be used in combination with new high-throughput strategies to identify the most preferred route correlating with desired metabolite biosynthesis in different plants under UV-B exposure experiments. Provided that models are validated to ensure they reflect reality in targeted increase in phytochemicals, this information will be of great value for identifying and increasing the health promoting effects of medicinal plants and predicting the cropping strategies on these plants in a changing global climate. This baseline information generated will be useful for the successful implementation of UV technology on a pilot scale, to benefit health conscious consumers, attributed to concurrent increase in different health-related constituents.

Future research studies are warranted to evaluate the effects of different doses/ exposure time of UV-B on the contents and health qualities of products in multiple cases which have not yet been investigated. Such data sets will provide a wealth of information to ecologists, plant breeders and agronomists.

10.1 Commercial Relevance

The fact, that solar UV-B regulates the secondary pathway of plants and improves plant metabolic functioning especially in aspects of food quality, pharmaceutical properties, pest and disease resistance. In this regard, UV-B supplementation

processing may be proven as a useful tool for plant manipulation in aspects of optimizes the nutritional/health value of herbal drugs and subsequently generate new opportunities by farmers and processors for achieving its rich quality and increased essential oil yield.

The information on health sensory constituents and antioxidant potential of medicinal and aromatic plants should be ever encouraged as it showed role on reduction of the risk of diseases. Phytochemistry study, as reported on medicinal and aromatic plants showed a positive induction of antioxidant compounds, such as polyphenols and flavonoids, essential oil yield and qualitative composition of oil in response to UV-B stressing. This enhancing effect of UV-B may be an interesting to follow in studying the phytotherapeutic activity of medicinal plants. In this review we provide an overview of medicinal property of various secondary metabolites, its responses to UV-B irradiation stimuli as well as reported pathway of secondary metabolic mechanism. Overall, the present article has added to our understanding of statutes and prospective of medicinal and aromatic plants, its health aspects on human life as well as positive response of UV-B to enhance nutritional value of plants via inducing possible enhancement in various health promoting constituents.

11 Conclusion

Short-term and moderate UV-B radiation seems to be a safe alternative as targeted treatment in medicinal and aromatic plants attributed to concurrent increase in different health-related constituents. In terms of sensory attributes as well as health benefits of valuable products of medicinal importance, these studies might contribute to provide a convenience and feasible approach to enhance the yield and qualitative value of these phytochemicals and subsequently generate new opportunities for growers and processors, for achieving the health-oriented herbal product market. In this respect, this may provide an innovation approach in pharmaceuticals drug technology. Hence, to determine relevant metabolic interactions between specific target metabolites and UV-B radiation may be a challenging task.

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References

- Afreen F, Zobayed SMA, Kozai T (2005) Spectral quality and UV-B stress stimulate glycyrrhizin concentration of *Glycyrrhiza uralensis* in hydroponic and pot system. *Plant Physiol Biochem* 43:1074–1081. doi:[10.1016/j.plaphy.2005.11.005](https://doi.org/10.1016/j.plaphy.2005.11.005)
- Agrawal SB, Rathore D (2007) Changes in oxidative stress defense system in wheat (*Triticum aestivum* L) and mung bean (*Vigna radiata* L) cultivars grown with and without mineral nutri-

- ents and irradiated by supplemental ultraviolet-B. *Environ Exp Bot* 59:21–33. doi:[10.1016/j.envexpbot.2005.09.009](https://doi.org/10.1016/j.envexpbot.2005.09.009)
- Agrawal SB, Singh S, Agrawal M (2009) UV-B induced changes in gene expression and antioxidants in plants. Chapter 3. *Adv Bot Res* 52:47–86
- Ali SS, Kasoju N, Luthra A, Singh A, Sharanabasava H, Sahu A, Bora U (2008) Indian medicinal herbs as sources of antioxidants. *Food Res Int* 41:1–15. doi:[10.1016/j.foodres.2007.10.001](https://doi.org/10.1016/j.foodres.2007.10.001)
- Alothman M, Bhat R, Karim AA (2009) Effects of radiation processing on phytochemicals and antioxidants in plant produce. *Trends Food Sci Technol* 20:201–212. doi:[10.1016/j.tifs.2009.02.003](https://doi.org/10.1016/j.tifs.2009.02.003)
- Arakawa O (1988) Photo-regulation of anthocyanin synthesis in apple fruit under UV-B and red light. *Plant Cell Physiol* 29(8):1385–1389
- Atmani D, Chafer N, Atmani D, Boudaoud H, Debache N, Berboucha M (2009) Flavonoids in human health: from structure to biological activity. *Curr Nutr Food Sci* 5: 225–237. doi: <http://dx.doi.org/10.2174/157340109790218049>
- Ayoola GA, Coker HAB, Adesegun SA, Adepoju-Bello AA, Obaweya K, Ezennia EC, Atangbayila TO (2008) Phytochemical screening and antioxidant activities of some selected medicinal plants used for Malaria therapy in Southwestern Nigeria. *Trop J Pharm Res* 7:1019–1024
- Beaulieu JC (2007) Effect of UV irradiation on cut cantaloupe: terpenoids and esters. *J Food Sci* 72(4):272–281. doi:[10.1111/j.1750-3841.2007.00327.x](https://doi.org/10.1111/j.1750-3841.2007.00327.x)
- Behn H, Albert A, Marx F, Noga G, Ulbrich A (2010) Ultraviolet-B and photosynthetically active radiation interactively affect yield and pattern of monoterpenes in leaves of peppermint (*Mentha x piperita* L.). *J Agr Food Chem* 58:7361–7367. doi:[10.1021/jf9046072](https://doi.org/10.1021/jf9046072)
- Binder BYK, Peebles CAM, Shanks JV, San K-Y (2009) The effects of UV-B stress on the production of terpenoid indole alkaloids in *Catharanthus roseus* hairy roots. *Biotechnol Prog* 25(3):861–865. doi:[10.1002/btpr.97](https://doi.org/10.1002/btpr.97)
- Bozin B, Mimica-Dukic N, Simin N, Anackov G (2006) Characterization of the volatile composition of essential oil of some lamiaceae species and the antimicrobial and antioxidant activities of the entire oils. *J Agric Food Chem* 54(5):1822–1828. doi:[10.1021/jf051922u](https://doi.org/10.1021/jf051922u)
- Canter PH, Thomas H, Ernst E (2005) Bringing medicinal plants into cultivation: opportunities and challenges for biotechnology. *Trends Biotechnol* 23:180–185. doi:[10.1016/j.tibtech.2005.02.002](https://doi.org/10.1016/j.tibtech.2005.02.002)
- Chan H-T, Chan C, Ho JW (2003) Inhibition of glycyrrhizic acid on aflatoxin B1-induced cytotoxicity in hepatoma cells. *Toxicology* 188:211–217. doi:[10.1016/S0300-483X\(03\)00087-8](https://doi.org/10.1016/S0300-483X(03)00087-8)
- Chanda S, Dave R (2009) *In vitro* models for antioxidant activity evaluation and some medicinal plants possessing antioxidant properties: an overview. *Afr J Microbiol Res* 3:981–996
- Chang X, Alderson PG, Wright CJ (2009) Enhanced UV-B radiation alters basil (*Ocimum basilicum* L) growth and stimulates the synthesis of volatile oils. *J Hortic For* 1:027–031
- Cirak C, Aksoy HM, Ayan AK, Saglam B, Kevseroglu K (2005) Enhanced hypericin production in *Hypericum perforatum* and *Hypericum pruinautum* in response to inoculation with two fungal pathogens. *Plant Protect Sci* 41:109–114
- Cui WH, Iwasa K, Tokuda H, Kashiwara A, Mitani Y, Hasegawa T, Nishiyama Y, Moriyasu M, Nishino H, Hanaoka M, Mukai C, Takeda K (2006) Potential cancer chemopreventive activity of simple isoquinolines, 1-benzylisoquinolinines, and protoberberines. *Phytochemistry* 67:70–79. doi:[10.1016/j.phytochem.2005.10.007](https://doi.org/10.1016/j.phytochem.2005.10.007)
- Dai J, Mumper RJ (2010) Plant phenolics: extraction, analysis and their antioxidant and anticancer properties. *Molecules* 15:7313–7352. doi:[10.3390/molecules15107313](https://doi.org/10.3390/molecules15107313)
- Desmarchelier C, Coussio J, Ciccio G (1998) Antioxidant and free radical scavenging effects in extracts of the medicinal herb *Achyrocline satureioides* (Lam) DC (“marcela”). *Braz J Med Biol Res* 31:1163–1170
- Deutsch AWV, Mitchell CD, Williams CE, Kamla Dutt K, Silvestrov NA, Klement BJ, Abukhalaf IK, Deutsch DAV (2005) Polyamines protect against radiation-induced oxidative stress. *Gravit Space Biol* 18(2):109–110
- Dolzhenko Y, Berteza CM, Occhipinti A, Bossi S, Maffei ME (2010) UV-B modulates the interplay between terpenoids and flavonoids in peppermint (*Mentha piperita* L.). *J Photochem Photobiol B Biol* 100:67–75. doi:[10.1016/j.jphotobiol.2010.05.003](https://doi.org/10.1016/j.jphotobiol.2010.05.003)

- Edreva A, Velikova V, Tsonev T, Dagnon S, Gürel A, Aktaş L, Gesheva E (2008) Stress-protective role of secondary metabolites: diversity of functions and mechanisms. *Gen Appl Plant Physiol* 34:67–78
- Eichholz I, Huyskens-Keil S, Keller A, Ulrich D, Kroh LW, Rohn S (2011) UV-B-induced changes of volatile metabolites and phenolic compounds in blueberries (*Vaccinium corymbosum* L.). *Food Chem* 126:60–64. doi:[10.1016/j.foodchem.2010.10.071](https://doi.org/10.1016/j.foodchem.2010.10.071)
- Farah A, Donangelo CM (2006) Phenolic compounds in coffee. *Braz J Plant Physiol* 18:23–36
- Fenglin H, Ruili L, Bao H, Liang M (2004) Free radical scavenging activity of extracts prepared from fresh leaves of selected Chinese medicinal plants. *Fitoterapia* 75:14–23. doi:[10.1016/j.fitote.2003.07.003](https://doi.org/10.1016/j.fitote.2003.07.003)
- Germ M, Stibilj V, Kreft S, Gaberščik A, Kreft I (2010) Flavonoid, tannin and hypericin concentrations in the leaves of St John's wort (*Hypericum perforatum* L.) are affected by UV-B radiation levels. *Food Chem* 122:471–474. doi:[10.1016/j.foodchem.2010.03.008](https://doi.org/10.1016/j.foodchem.2010.03.008)
- Gil M, Pontin M, Berli F, Bottini R, Piccoli P (2012) Metabolism of terpenes in the response of grape (*Vitis vinifera* L.) leaf tissues to UV-B radiation. *Phytochemistry* 77:89–98. doi:[DOI:10.1016/j.phytochem.2011.12.011](https://doi.org/10.1016/j.phytochem.2011.12.011)
- Gill SS, Tuteja N (2010) Polyamines and abiotic stress tolerance in plants. *Plant Signal Behav* 5(1):26–33
- Gomes A, Fernandes E, Lima JLFC, Mira L, Corvo ML (2008) Molecular mechanisms of anti-inflammatory activity mediated by flavonoids. *Curr Med Chem* 15:1586–1605
- Gonthier M-P, Verny M-A, Besson C, Révész C, Scalbert A (2003) Chlorogenic acid bioavailability largely depends on its metabolism by the gut microflora in rats. *J Nutr* 133:1853–1859
- González-Gallego J, Sánchez-Campos S, Tuñón MJ (2007) Antiinflammatory properties of dietary flavonoids. *Nutr Hosp* 22:287–293
- Gregianini TS, de Silveira VC, Porto DD, Kerber VA, Henriques AT, Fett-Neto A-G (2003) The alkaloid brachycerine is induced by ultraviolet radiation and is a singlet oxygen quencher. *Photochem Photobiol* 78(5):470–474. doi:[10.1562/0031-8655\(2003\)0780470TABIIB2.0.CO2](https://doi.org/10.1562/0031-8655(2003)0780470TABIIB2.0.CO2)
- Guo J, Han W, Wang M-H (2008) Ultraviolet and environmental stresses involved in the induction and regulation of anthocyanin biosynthesis: a review. *Afr J Biotechnol* 7(25):4966–4972
- Hagen SF, Borge GIA, Bengtsson GB, Bilger W, Berge A, Haffner K, Solhaug KA (2007) Phenolic contents and other health and sensory related properties of apple fruit (*Malus domestica* Borkh, cv Aroma): effect of postharvest UV-B irradiation. *Postharvest Biol Technol* 45:1–10. doi:[10.1016/j.postharvbio.2007.02.002](https://doi.org/10.1016/j.postharvbio.2007.02.002)
- Halliwell B (1994) Free radicals and antioxidants: a personal view. *Nutr Rev* 52:253–265
- Hampel D, Mosandl A, Wüst M (2005) Induction of de novo volatile terpene biosynthesis via cytosolic and plastidial pathways by methyl jasmonate in foliage of *Vitis vinifera* L. *J Agric Food Chem* 53(7):2652–2657. doi:[10.1021/jf040421q](https://doi.org/10.1021/jf040421q)
- Hectors K, Prinsen E, De Coen W, Jansen MAK, Guisez Y (2007) *Arabidopsis thaliana* plants acclimated to low dose rates of ultraviolet B radiation show specific changes in morphology and gene expression in the absence of stress symptoms. *New Phytol* 175(2):255–270
- Higashio H, Hirokane H, Sato F, Tokuda S, Uragami A (2007) Enhancement of functional compounds in *Allium* vegetables with UV radiation. *Acta Hort* 744:357–361
- Hirata K, Asada M, Yatani E, Miyamoto K, Miura Y (1993) Effects of near-ultraviolet light on alkaloid production in *Catharanthus roseus* plants. *Planta Med* 59(1):46–50
- Holst B, Williamson G (2004) A critical review of the bioavailability of glucosinolates and related compounds. *Nat Prod Rep* 21:425–447. doi:[10.1039/B204039P](https://doi.org/10.1039/B204039P)
- Interdonato R, Rosa M, Nieva CB, González JA, Hilal M, Prado FE (2011) Effects of low UV-B doses on the accumulation of UV-B absorbing compounds and total phenolics and carbohydrate metabolism in the peel of harvested lemons. *Environ Exp Bot* 70:204–211. doi:[10.1016/j.envexpbot.2010.09.006](https://doi.org/10.1016/j.envexpbot.2010.09.006)
- Ioannidis D, Bonner L, Johnson CB (2002) UV-B is required for normal development of oil glands in *Ocimum basilicum* L (sweet basil). *Ann Bot* 90(4):453–460. doi:[10.1093/aob/mcf212](https://doi.org/10.1093/aob/mcf212)
- Jain VC, Patel NM, Shah DP, Patel PK, Joshi BH (2010) Antioxidant and antimicrobial activities of *Alangium salvifolium* (LF) Wang root. *Global J Pharmacol* 4(1):13–18

- Jang M, Cai L, Udeani GO, Slowing KV, Thomas CF, Beecher CWW, Fong HHS, Farnsworth NR, Kinghorn AD, Mehta RG, Moon RC, Pezzuto JM (1997) Cancer chemopreventive activity of resveratrol, a natural product derived from grapes. *Science* 275:218–220. doi:[10.1126/science.275.5297.218](https://doi.org/10.1126/science.275.5297.218)
- Jansen MAK, Hectors K, O'Brien NM, Guisez Y, Potters G (2008) Plant stress and human health: do human consumers benefit from UV-B acclimated crops. *Plant Sci* 175:449–458. doi:[10.1016/j.plantsci.2008.04.010](https://doi.org/10.1016/j.plantsci.2008.04.010)
- Johnson CB, Kirby J, Naxakis G, Pearson S (1999) Substantial UV-B-mediated induction of essential oils in sweet basil (*Ocimum basilicum* L). *Phytochemistry* 51(4):507–510
- Kala CP, Dhyani PP, Sajwan BS (2006) Developing the medicinal plants sector in northern India: challenges and opportunities. *J Ethnobiol Ethnomed* 2:32. doi:[10.1186/1746-4269-2-32](https://doi.org/10.1186/1746-4269-2-32)
- Kanadaswami C, Lee L-T, Lee P-PH, Hwang JJ, F-C KE, Huang Y-T, Lee M-T (2005) The antitumor activities of flavonoids. *In Vivo* 19:895–910
- Karousou R, Grammatikopoulos G, Lanaras T, Manetas Y, Kokkini S (1998) Effect of enhanced UV-B radiation on *Mentha spicata* essential oil. *Phytochemistry* 49:2273–2277
- Kasige A, Takashi A (2009) Carbon and nitrogen partitioning in the freshwater submerged macrophyte *Vallisneria spiralis* in response to ultraviolet-B irradiance. *Aquat Ecol* 43(2):313–322. doi:[10.1007/s10452-008-9201-z](https://doi.org/10.1007/s10452-008-9201-z)
- Kaur GJ, Arora DS (2009) Antibacterial and phytochemical screening of *Anethum graveolens*, *Foeniculum vulgare* and *Trachyspermum ammi*. *BMC Complement Altern Med* 9:30. doi:[10.1186/1472-6882-9-30](https://doi.org/10.1186/1472-6882-9-30)
- Kaur P, Singh B, Kumar S, Kaur S (2008) In vitro evaluation of free radical scavenging activity of *Rubia cordifolia* L. *J Chin Clin Med* 3:278–284
- Kim BG, Kim JH, Kim J, Lee C, Ahn J-H (2008) Accumulation of flavonols in response to ultraviolet-b irradiation in soybean is related to induction of flavanone 3- β -hydroxylase and flavonol synthase. *Mol Cells* 25:247–252
- Kong J-M, Chia LS, Goh NK, Chia TF, Brouillard R (2003) Analysis and biological activities of anthocyanins. *Phytochemistry* 64:923–933. doi:[10.1016/S0031-9422\(03\)00438-2](https://doi.org/10.1016/S0031-9422(03)00438-2)
- Korkina LG (2007) Phenylpropanoids as naturally occurring antioxidants: from plant defense to human health. *Cell Mol Biol* 53(1):15–25. doi:[10.1170/T772](https://doi.org/10.1170/T772)
- Kramer GF, Norman HA, Krizek DT, Mirecki RM (1991) Influence of UV-B radiation on polyamines, lipid peroxidation and membrane lipids in cucumber. *Phytochemistry* 30:2101–2108
- Krishnaiah D, Sarbatly R, Bono A (2007) Phytochemical antioxidants for health and medicine – a move towards nature. *Biotechnol Mol Biol Rev* 2(4):097–104
- Kshirsagar R, Upadhyay S (2009) Free radical scavenging activity screening of medicinal plants from Tripura, northeastern India. *Nat Prod Rad* 8:117–122
- Kuhlmann F, Muller C (2009) Independent responses to ultraviolet radiation and herbivore attack in broccoli. *J Exp Bot* 60:3467–3475. doi:[10.1093/jxb/erp182](https://doi.org/10.1093/jxb/erp182)
- Kumari R, Agrawal SB, Sarkar A (2009a) Evaluation of changes in oil cells and composition of essential oil in lemongrass (*Cymbopogon citratus* (DC) Stapf) due to supplemental ultraviolet-B irradiation. *Curr Sci* 97:1137–1142
- Kumari R, Singh S, Agrawal SB (2009b) Combined effects of psoralens and ultraviolet-B on growth, pigmentation and biochemical parameters of *Abelmoschus esculentus* L. *Ecotoxicol Environ Safety* 72:1129–1136. doi:[10.1016/j.ecoenv.2008.12.009](https://doi.org/10.1016/j.ecoenv.2008.12.009)
- Kumari R, Agrawal SB, Singh S, Dubey NK (2009c) Supplemental ultraviolet-B induced changes in essential oil composition and total phenolics of *Acorus calamus* L (Sweet flag). *Ecotoxicol Environ Safety* 72:2013–2019. doi:[10.1016/j.ecoenv.2009.02.006](https://doi.org/10.1016/j.ecoenv.2009.02.006)
- Kumari R, Agrawal SB (2010) Comparative analysis of essential oil composition and oil containing glands in *Ocimum sanctum* L (Holy basil) under ambient and supplemental level of UV-B through Gas chromatography–mass spectrometry (GC-MS) and Scanning electron microscopy (SEM). *Acta Physiol Plant* 33:1093–1110. doi:[10.1007/s11738-010-0637-0](https://doi.org/10.1007/s11738-010-0637-0)
- Kuznetsov VV, Shevyakova NI (2007) Polyamines and stress tolerance of plants. *Plant Stress* 1:50–71
- Larson RA (1988) The antioxidants of higher plants. *Phytochemistry* 27:969–978

- Li X, Zheng X, Yan S, Li S (2008) Effects of salicylic acid (SA), ultraviolet radiation (UV-B and UV-C) on trans-resveratrol inducement in the skin of harvested grape berries. *Front Agric Chin* 2(1):77–81. doi:[10.1007/s11703-008-0014-6](https://doi.org/10.1007/s11703-008-0014-6)
- Liu F, Ng TB (2000) Antioxidative and free radical scavenging activities of selected medicinal herbs. *Life Sci* 66:725–735
- Long JC, Jenkins GI (1998) Involvement of plasma membrane redox activity and calcium homeostasis in the UV-B and UV-A/blue light induction of gene expression in Arabidopsis. *Plant Cell* 10:2077–2086
- Luis JC, Perez RM, Gonzalez FV (2007) UV-B radiation effects on foliar concentrations of rosmarinic and carnosic acids in rosemary plants. *Food Chem* 101:1211–1215. doi:[10.1016/j.foodchem.2006.03.023](https://doi.org/10.1016/j.foodchem.2006.03.023)
- Mackerness A-HS, Thomas B (1999) Effects of UV-B radiation on plants: gene expression and signal transduction pathways. In: Smallwood MF, Calvert CM, Bowles DJ (eds) *Plant responses to environmental stress*. Bios Scientific, Oxford, pp 10–23
- Maffei M, Scannerini S (2000) UV-B effect on photomorphogenesis and essential oil composition in peppermint (*Mentha piperita* L.). *J Essent Oil Res* 12(5):523–529. doi:[10.1080/10412905.2000.9712150](https://doi.org/10.1080/10412905.2000.9712150)
- Majhenic L, Skerget M, Knez Z (2007) Antioxidant and antimicrobial activity of guarana seed extracts. *Food Chem* 104:1258–1268. doi:[10.1016/j.foodchem.2007.01.074](https://doi.org/10.1016/j.foodchem.2007.01.074)
- Malik AA, Suryapani S, Ahmad J (2011) Chemical vs organic cultivation of medicinal and aromatic plants: the choice is clear. *Int J Med Arom Plants* 1:5–13
- Mata AT, Proenca C, Ferreira AR, Serralheiro MLM, Nogueira JMF, Araujo MEM (2007) Antioxidant and antiacetylcholinesterase activities of five plants used as Portuguese food species. *Food Chem* 103:778–786. doi:[10.1016/j.foodchem.2006.09.017](https://doi.org/10.1016/j.foodchem.2006.09.017)
- Moura DJ, Richter MF, Boeira JM, Henriques JAP, Saffi J (2007) Antioxidant properties of β -carboline alkaloids are related to their antimutagenic and antigenotoxic activities. *Mutagenesis* 22:293–302. doi:[10.1093/mutage/gem016](https://doi.org/10.1093/mutage/gem016)
- Nambiar VS, Daniel M, Guin P (2010) Characterization of polyphenols from coriander leaves (*Coriandrum sativum*), red amaranthus (*A Paniculatus*) and green amaranthus (*A frumentaceus*) using paper chromatography: and their health implications. *J Herbal Med Toxicol* 4:173–177
- Nassar Z, Aisha A, Abdul Majid A (2010) The pharmacological properties of terpenoids from *Sandoricum Koetjape* Webmed. *Cent Complement Med* 1:WMC001311
- Nishimura T, Ohyama K, Goto E, Inagaki N, Morota T (2008) Ultraviolet-B radiation suppressed the growth and anthocyanin production of *Perilla* plants grown under controlled environments with artificial light. *ISHS Acta Hortic* 797: international workshop on greenhouse environmental control and crop production in semi-arid regions
- Nitz GM, Schnitzler WH (2004) Effect of PAR and UV-B radiation on the quality and quantity of the essential oil in sweet basil (*Ocimum basilicum* L.). *Acta Hortic* (ISHS) 659:375–381
- Ouwerkerk PBF, Hallard D, Verpoorte R, Memelink J (1999) Identification of UV-B light-responsive regions in the promoter of the tryptophan decarboxylase gene from *Catharanthus roseus*. *Plant Mol Biol* 41(4):491–503. doi:[10.1023/A:1006321100550](https://doi.org/10.1023/A:1006321100550)
- Paduch R, Kandfer-Szersze M, Trytek M, Fiedurek J (2007) Terpenes: substances useful in human healthcare. *Arch Immunol Ther Exp* 55(5):315–327
- Paiva S, Russell R (1999) Beta carotene and other carotenoids as antioxidants. *J Am Coll Nutr* 18:426–433
- Patel VR, Patel PR, Kajal SS (2010) Antioxidant activity of some selected medicinal plants in western region of India. *Adv Biol Res* 4:23–26
- Petersen OH, Spät A, Verkhatsky A (2005) Introduction: reactive oxygen species in health and disease. *Philos Trans R Soc B* 360:2197–2199. doi:[10.1098/rstb.2005.1776](https://doi.org/10.1098/rstb.2005.1776)
- Pourmorad F, Hosseinimehr SJ, Shahabimajid N (2006) Antioxidant activity, phenol and flavonoid contents of some selected Iranian medicinal plants. *Afr J Biotechnol* 5:1142–1145
- Prakash D, Samiksha S, Upadhyay G, Singh BN (2007) Total phenol, antioxidant and free radical scavenging activities of some medicinal plants. *Int J Food Sci Nutr* 58:18–28

- Rai R, Meena RM, Smita SS, Shukla A, Rai SK, Rai SP (2011) UV-B and UV-C pre-treatments induce physiological changes and artemisinin biosynthesis in *Artemisia annua* L – an antimalarial plant. *J Photochem Photobiol B Biol* 105:216–225. doi:10.1016/j.jphotobiol.2011.09.004
- Ramani S, Chelliah J (2007) UV-B-induced signaling events leading to enhanced-production of catharanthine in *Catharanthus roseus* cell suspension cultures. *BMC Plant Biol* 7:61. doi:10.1186/1471-2229-7-61
- Ramani S, Jayabaskaran C (2008) Enhanced catharanthine and vindoline production in suspension cultures of *Catharanthus roseus* by ultraviolet-B light. *J Mol Signal* 3:9. doi:10.1186/1750-2187-3-9
- Ramani R, Patil N, Jayabaskaran C (2010) UV-B induced transcript accumulation of DAHP synthase in suspension-cultured *Catharanthus roseus* cells. *J Mol Signal* 5:13. doi:10.1186/1750-2187-5-13
- Ravindran KC, Indrajith A, Balakrishnan V, Venkatesan K, Kulandaivelu G (2010) Determination of defense mechanism in *Phaseolus trilobus* Ait seedlings treated under UV-B radiation. *Af Crop Sci J* 16:111–118
- Rice-Evans CA, Miller NJ, Bolwell PG, Gramley PM, Pradham JB (1995) The relative antioxidant activities of plant derived polyphenolic flavonoids. *Free Radic Res* 22:375–383
- Ross JA, Kasum CM (2002) Dietary flavonoids: bioavailability, metabolic effects, and safety. *Annu Rev Nutr* 22:19–34. doi:10.1146/annurev.nutr.22.111401.144957
- Sanclemente T, Marques-Lopes I, Puzo J, Garcia-Qtin AL (2009) Role of naturally-occurring plant sterols on intestinal cholesterol absorption and plasmatic levels. *J Physiol Biochem* 65:87–98. doi:10.1007/BF03165972
- Schippmann U, Leaman DJ, Cunningham CB (2002) Impact of cultivation and gathering of medicinal plants in biodiversity: global trends and issues In: FAO ed Biodiversity and the ecosystem approach in agriculture, forestry, and fisheries, FAO, Interdepartmental working group on biological diversity for food and agriculture. Rome, pp 142–167
- Schreiner M, Krumbein A, Mewis I, Ulrichs C, Huyskens-Keil S (2009) Short-term and moderate UV-B radiation effects on secondary plant metabolism in different organs of nasturtium (*Tropaeolum majus* L). *Innov Food Sci EmergTech* 10:93–96. doi:10.1016/j.ifset.2008.10.001
- Shetty P (2011) Indian generics giants set sights on Japan. *Nature*. doi:10.1038/news.2011.377
- Singh K, Kumar S, Rani A, Gulati A, Ahuja PS (2009) Phenylalanine ammonia-lyase (PAL) and cinnamate 4-hydroxylase (C4H) and catechins (flavan-3-ols) accumulation in tea. *Funct Integr Genom* 9(1):125–134. doi:10.1007/s10142-008-0092-9
- Souri E, Amin G, Farsam H, Jalalizadeh H, Barezi S (2008) Screening of thirteen medicinal plant extracts for antioxidant activity. *Iran J Pharm Res* 7:149–154
- Sperandio O, Fan BT, Zakrzewska K, Jia ZJ, Zheng RL, Panaye A, Doucet JP, Fassi NE (2002) Theoretical study of fast repair of DNA damage by cistanoside C and analogs: mechanism and docking. *SAR QSAR Environ Res* 13:243–260
- Stintzing FC, Carle R (2004) Functional properties of anthocyanins and betalains in plants, food, and in human nutrition. *Trends Food Sci Technol* 15:19–38. doi:10.1016/j.tifs.2003.07.004
- Sun M, Gu X, Fu H, Zhang L, Chen R, Cui L, Zheng L, Zheng D, Tian J (2010) Change of secondary metabolites in leaves of *Ginkgo biloba* L in response to UV-B induction. *Innov Food Sci Emerg Technol* 11:672–676. doi:10.1016/j.ifset.2010.08.006
- Sung J-K, Lee S-Y, Park JH, Lee S-M, Lee YH, Choil D-H, Kim T-W, Song B-H (2008) Changes in carbohydrate, phenolics and polyamines of pepper plants under elevated UV-B radiation. *Korean J Soil Sci Fert* 41:38–43
- Tadeusz A (2007) Alkaloids-secrets of life: alkaloid chemistry, biological significance, applications and ecological role. Elsevier Science and Technology, Oxford, pp 141–158
- Tepe B, Daferera D, Tepe A, Polissiou M, Sokmen A (2007) Antioxidant activity of the essential oil and various extracts of *Nepta flavida* Hud-Mor from Turkey. *Food Chem* 103:1358–1364
- Textor S, Gershenzon J (2009) Herbivore induction of the glucosinolates-myrosinase defense system: major trends, biochemical basis and ecological significance. *Phytochem Rev* 8:149–170. doi:10.1007/s11101-008-9117-1

- Thoppil RJ, Bishayee A (2011) Terpenoids as potential chemopreventive and therapeutic agents in liver cancer. *World J Hepatol* 3:228–249. doi:[10.4254/wjh.v3.i9.228](https://doi.org/10.4254/wjh.v3.i9.228)
- Tumova L, Tuma J (2011) The effect of UV light on isoflavonoid production in *Genista tinctoria* culture in vitro. *Acta Physiol Plant* 33(2):635–640. doi:[10.1007/s11738-010-0566-y](https://doi.org/10.1007/s11738-010-0566-y)
- Ubi BE, Honda C, Bessho H, Kondo S, Wada M, Kobayashi S, Moriguchi T (2006) Expression analysis of anthocyanin biosynthetic genes in apple skin: effect of UV-B and temperature. *Plant Sci* 170(3):571–578. doi:[10.1016/j.plantsci.2005.10.009](https://doi.org/10.1016/j.plantsci.2005.10.009)
- Uniyal RC, Uniyal MR, Jain P (2000) Cultivation of medicinal plants in India. A reference book, – New Delhi, TRAFFIC India & WWF India
- Vines G (2004) Herbal harvests with a future: towards sustainable sources for medicinal plants, Plant life, International; www.plantlife.uk
- Wang Y, Xu W-J, Yan X-F, Wang Y (2011) Glucosinolate content and related gene expression in response to enhanced UV-B radiation in *Arabidopsis*. *Afric J Biotechnol* 10(34):6481–6491
- Wannissorn B, Jarikasem S, Siriwangchai T, Thubthimthed S (2005) Antibacterial properties of essential oils from Thai medicinal plants. *Fitoterapia* 76:233–236. doi:[10.1016/j.fitote.2004.12.009](https://doi.org/10.1016/j.fitote.2004.12.009)
- Wei A, Shibamoto T (2007) Antioxidant activities and volatile constituents of various essential oils. *J Agric Food Chem* 55(5):1737–1742
- WHO (2002) WHO traditional medicine strategy 2002–2005. World Health Organization, Geneva
- Wiersum KF, Dold AP, Husselman M, Cocks M (2006) Cultivation of medicinal plants as a tool for biodiversity conservation and poverty alleviation in the Amatola region, South Africa Forest and nature conservation policy group. Wageningen University, Netherlands
- World Health Organization (WHO) (2003) WHO guidelines for good agricultural and collection practices (GACP) for medicinal plants. whqlibdoc.who.int/publications/2003/9241546271.pdf
- Woyengo TA, Ramprasath VR, Jones PJH (2009) Anticancer effects of phytosterols. *Europ J Clin Nutr* 63:813–820
- Yamunadevi M, Wesely EG, Johnson M (2011) Phytochemical studies on the terpenoids of medicinally important plant *Aerva lanata* L using HPTLC. *As Pac J Trop Biomed* 1:220–225
- Zakaria ZA (2007) Free radical scavenging activity of some plants available in Malaysia. *Iran J Pharmacol Ther IJPT* 6:87–91
- Zangerl AR, Berenbaum MR (1987) Furanocoumarins in wild parsnip: effects of photosynthetically active radiation, ultraviolet light and nutrition. *Ecology* 68(3):516–520
- Zhang WJ, Björn LO (2009) The effect of ultraviolet radiation on the accumulation of medicinal compounds in plants. *Fitoterapia* 80:207–218. doi:[10.1016/j.fitote.2009.02.006](https://doi.org/10.1016/j.fitote.2009.02.006)
- Zhang Q, Ye M (2009) Chemical analysis of the Chinese herbal medicine Gan–Cao (licorice). *J Chromatogr A* 1216:1954–1969. doi:[10.1016/j.chroma.2008.07.072](https://doi.org/10.1016/j.chroma.2008.07.072)
- Zheng XQ, Jin J, Chen H, Du YY, Ye JH, Lu JL, Lin C, Dong JJ, Sun QL, Wu LY, Liang YR (2008) Effect of ultraviolet B irradiation on accumulation of catechins in tea (*Camellia sinensis* (L) O Kuntze). *Afric J Biotechnol* 7:3283–3287
- Zu Y-G, Pang H-H, Yu J-H, Li D-W, Wei X-X, Gao Y-X, Tong L (2010) Responses in the morphology, physiology and biochemistry of *Taxus chinensis* var *mairei* grown under supplementary UV-B radiation. *J Photochem Photobiol B Biol* 98:152–158. doi:[10.1016/j.jphotobiol.200](https://doi.org/10.1016/j.jphotobiol.200)