International Journal of Plant and Environment
Vol. 4, No. 2 (July, 2018), 50-59

Impact of Light Stress on Plant Based Medicinally Active Compounds

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Publication Info

Article history:
Received: 09.03.2018
Accepted: 16.07.2018
DOI: 10.18811/ ijpen.v4i02.6

Key words:
Alkaloids
Essential oil
Light stress
Medicinal plants
Photosystem II.
Supplemental UV-B (sUV-B)

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Abstract

Light has several positive and negative impacts on plant growth and physiological processes. Medicinal plants contribute significantly higher proportions of world plant flora and are natural source of rich medicinal compounds. Sufficient literature is available on plant responses to light stress but studies on medicinal plants are limited. This review discusses how different light conditions affect production of plant-based medicinal compounds which are broadly secondary products formed during adverse environmental conditions to cope up the stress. Here, some medicinal plants are reviewed which were exposed to different light conditions including blue light, red light, yellow light, green light, far red light, wavelength specific light treatments, pulsed pre light, specific light intensity, light shade treatments, and supplemental ultraviolet-B radiation. Secondary metabolites considered for the review are anthocyanin, flavonoids, alkaloids, essential oils, cannabinoids and glucosinolates. Most of the results revealed increase in content of medicinal compounds under differentially exposed light conditions with maximum effect under sUV-B exposure. Advancement in the knowledge of medicinal plants response to light stress can help in understanding the mechanism of medicinal compound formation and their regulation which can be further utilized in the production of medicinally active compounds.

1. Introduction

Light received from the sun is the driving force for all life forms on Earth and is the key energy source for biomass production through photosynthetic electron transport as it is the only way by which plants derive their energy. Plant requires light for survival which fuels the plant in form of photosynthesis, and it affects different growth stages of the plant throughout the duration of light delivered each day (https://www.farmersweekly.co). Light duration and time affects germination, green leafy vegetative stage, and also the blooming stage of plants. Also, the specific wavelength of light is essential for the formation of specific compounds and pigments in plants, e.g. blue light and red light in combination promotes flowering (https://www.farmersweekly.co). Light has also several impacts on direction and orientation in plants. Generally, plant stems are positively phototrophic and roots are negatively phototrophic. Seasonal changes in plants are also dependent on light. Besides, it also regulates the various signaling mechanism for plant development and to position successful defensive response by stimulation of various defense-related secondary metabolites under different environmental stresses. Light is an essential energy source for all photosynthetic plants but since it is a highly energetic substrate it may cause negative impacts on photosynthesis as it damages photosystem II (PS II) leading to photo-inhibition. Light is an important factor for inducing growth and organogenesis and also necessary for producing primary and secondary metabolites in plants. Generally, plants produce various kinds of secondary products in different adverse environmental condition to cope up the damages. These secondary metabolites are of different chemical compositions and specific nature while light has stimulatory effects on production and regulation of these compounds such as flavonoids and anthocyanin pigments of plants (Shohael *et al*., 2006). Light stress includes excess light energy, different spectral radiation, UV radiation and also ionizing radiation. Light has also an inhibitory effect on the accumulation of secondary products such as nicotine and shikonin (Liu *et al*., 2002). Light is also involved in the formation of secondary products zingiberene and gingerole from *Zingiber officinale* callus culture. Increase in phenolics due to increasing light intensities has also been reported (Akula and Ravishankar, 2011).

Supplemental ultraviolet-B radiation (sUV-B) functions as induction factor for production of antioxidative defense-related secondary metabolite which functions as antioxidants, chemical signals, growth regulators and UV-B screens and their levels are up-regulated to counteract the damaging effect of UV-B (Takshak and Agrawal, 2015a). Ultraviolet radiation has pronounced effect on secondary metabolites production as it is involved in the regulation of key enzymes, phenylalanine ammonia lyase (PAL) and chalcone synthase (CHS) of phenylpropanoid pathway (Afreen *et al*., 2005). In some of the studies, it has been reported that the blue light induced anthocyanin formation in strawberry cells, whereas red light hardly affected it (Afreen *et al*., 2005). Glycyrrhizin concentrations in the roots of three-month-old plant were significantly increased due to UV exposure (Afreen *et al*., 2005). The mechanism for secondary metabolite production in *Glycyrrhiza* due to light induction had been investigated

(Kurata *et al*., 1997). Light irradiation induced the production of purine alkaloid in *Caeffia arabica* cells besides, it also caused physiological and metabolic changes. Here, light irradiation plays two important role in purine alkaloid formation (i) light induces the methyltransferase activity in relatively short time and (ii) stress for primary metabolites that result in accumulation of purine rings which are the skeleton for the formation of purine alkaloids (Kurata *et al*., 1997). Secondary metabolites had a sun-screening effect and protect cells from excess light by its accumulation in epidermis or superficial tissues under which flavonoids are well- known UV screens and generally localized on the light exposed tissues while alkaloids that are not only UV absorbing chemical compounds but also depict toxicity (Zhang and Björn, 2009). Percentage increase in alkaloid containing plant flora near the equator has been reported but without much evidence one could not claim that it was totally a protective role against radiation (Zhang and Björn, 2009).

2. Medicinal Plants and their Importance

Since, long times many plants have been known for their medicinal properties and used by human beings in primary health care. It is as ancient as human civilization. Nowadays, renewed interest in consumption of herbal medicine is being developed due to various side effects and extravagant chemical drugs (Kumari and Prasad, 2013). Several diseases are generated due to the generation of free radicals and reactive oxygen species and as we know that medicinal plants are a good source of natural antioxidants, they are used to treat diseases throughout the world (Chikezie and Ojiako, 2015). Many of the commercially used drugs are synthetic formulation of plant secondary products and people utilize them as they have low cost and also impart no side effects (Kumari and Prasad, 2013). According to World Health Organization (2001), 80% of the population of developing countries uses herbal medicines for primary health care. Nowadays, due to beneficial effects of natural antioxidants in the prevention of diseases interest in plant based drugs increasing continuously (Kopaei, 2012). High light stress and sUV-B is also a kind of stress that is not overcome by any secondary management as it is a part of solar radiation. As reported previously medicinal plants directly or indirectly contributes about 25% of prescribed medicines (Fakim, 2006). Therefore, we should discuss the impact of these stresses on medicinal plants which can be harmful if received at a higher dose.

The world is graced with a rich wealth of medicinal plants. It is recorded that around 70,000 species from lichens to towering trees, have been used at single or multiple times for medicinal purposes (State of World's plant, 2017). Drug discoveries from medicinal plants led to the identification and isolation of early drugs, for example, isolation of morphine from opium in the early 19th century and cocaine, codeine, digitoxin and quinine which are still in use (Teramura and Sullivan, 1994). At present, 28,187 plant species have been documented possessing medicinal properties. According to WHO (2003), the estimated annual global market for herbal medicine to be worth US$60 billion in 2003 and by 2050 it is projected to reach US$5 trillion. It was estimated that fewer than 16% (4,478) of the species used in plant based medicines are cited in medicinal regulatory publications (State of World's plant, 2017). Several ancient medicines are the source of modern allopathic medicines used in treating new diseases therefore it is important to discover new remedies that will be commercialized in near future (Fakim, 2006). Among 20 largest plant families twelve of them have a significantly higher proportion of medicinal plants than would be anticipated if distributions across families are even, among which seven families that alone contributes 89.9% of medicinal plants (Table 1). Families Moraceae and Apocynaceae contribute 22.2% and 13.5%, respectively, of species out of total plants of these families (Table 2). A plant of Moraceae family known as mulberry contains imino sugar which is used in the treatment of diabetes. Vincristine and vinblastine are important anticancerous drugs derived from *Catharanthus roseus* belongs to the family Apocynaceae. An anti-blood clotting drug warfarin is derived from a coumarin from sweet clover *(Melilotus officinalis)* in the Fabaceae family that contributes 11.2% medicinal plants out of total plants in this family (Table 2) (State of World's plant, 2017). These three families (Moraceae, Apocynaceae, and Fabaceae) are very important on the medicinal point of view but there are also other families which

Table 1: Plant families that contribute higher percentage of medicinal plants with their specific medicinal compounds.

Family	Total number of plant species	Total number of medicinal plants (%)	Key class of specific medicinal compounds found in each family
Fabaceae	20,856	11.2	Alkaloids
Lamiaceae	7,756	13.7	Terpenes
Euphorbiaceae	6,407	13.5	Diterpenoids
Apocynaceae	6,341	13.5	Cardiac-glycosides
Malvaceae	5,329	11.7	Organic acids
Apiaceae	4,079	14.4	Coumarins
Ranunculaceae	3,640	11.9	Alkaloids

Table 2: Higher percentage of medicinal plants contributed by some plant families.

S.N.	Family	Percentage of plant species in families used for medicinal purposes
1	Moraceae	22.5%
2	Apiaceae	14.4%
3	Lamiaceae	13.7%
4	Solanaceae	13.6%
5	Euphorbiaceae	13.5%
6	Apocynaceae	13.5%
7	Rutaceae	13.5%
8	Ranunculaceae	11.9%
9	Annonaceae	11.9%
10	Asparagaceae	11.8%
11	Malvaceae	11.7%
12	Fabaceae	11.2%

show higher percentage of plants with medicinal applications (Table 2) (State of World's plant, 2017).

Some commercially useful secondary metabolites are nicotine, pyrethrins, and rotenones which are used in pesticides in limited quantities, beside it some specific alkaloids and steroids are used in drug manufacturing in the pharmaceutical companies (Balandrin *et al*., 1985). Secondary metabolites of plants have no significant role in plant primary metabolism but they play different secondary roles in plants which are of ecological nature, for example, they are important part of plant's self-defense system, and they are also restricted to specific taxonomic group (class, order, family, genus and species) (Balandrin *et al*., 1985). From the previous discoveries it has been estimated that only 5 to 15% of higher plants has been identified for biologically active compounds (Balandrin *et al*., 1985). Traditional knowledge of medicinal plants opens a new door of novel drug discoveries from plants based medicinal compounds.

In C4 plant, PEP*case* is the primary CO_2 fixing enzymes that determine their photosynthetic efficiency, which was greatly enhanced under high light intensities while photosynthetic oxygen evolution was unaffected (Jagtap *et al*., 1998). Exposure to high light intensities showed chlorophyll degradation which led to a marked decline in photosynthetic efficiency of PS II and considerable degradation of Rubisco in both susceptible and tolerant varieties, and to counteract these damages plants developed structural modifications in photosynthetic apparatus (Jagtap *et al*., 1998). In an experiment, globular somatic embryos of *Eleutherococcus senticosus* were treated with five different radiation treatments: dark (as control), fluorescent (FI), monochromatic red (peak emission 660 nm), monochromatic blue (peak emission 470nm), blue plus far-red light emitting diodes (Shohael *et al*., 2006). The growth of the somatic embryos were significantly affected under these light conditions (Shohael *et al*., 2006). An experiment conducted for high light stress, given by continuous white light with the help of slide projector on leaves of soybean plant *(Glycine max)* for

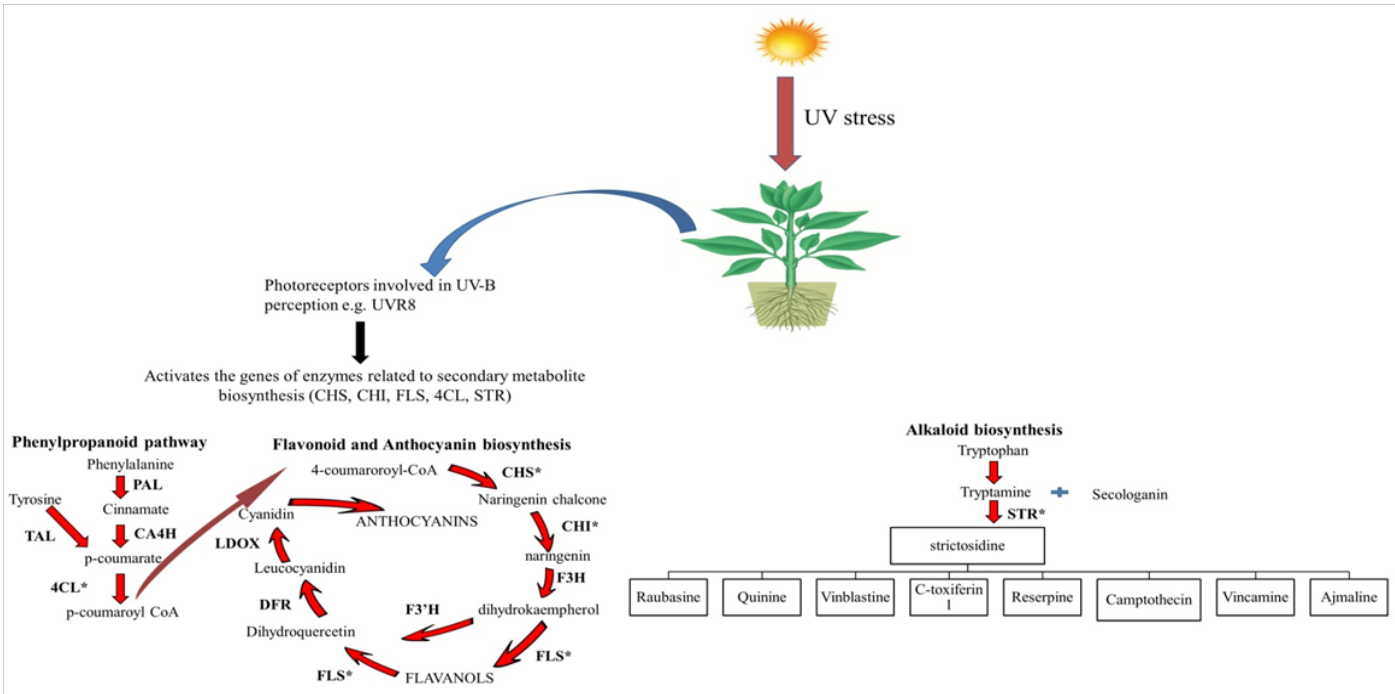

Fig. 1: UV induced phenylpropanoid pathway (modified from Dixon and Paiva, 1995), flavanoid, anthocyanin biosynthesis in Arabidopsis thaliana (modified from Xing et al., 2014) and indole alkaloid biosynthesis in plants (modified from Takshak and Agrawal, 2014 and Ma et al., 2006). * indicates the enzymes induced by UV stress and further involved in secondary metabolites biosynthesis. UVR8, UV RESISTANCE LOCUS 8; HY5, ELONGATED HYPOCOTYL 5; CHS, CHALCONE SYNTHASE; CHI, CHALCONE ISOMERASE; F3H, FLAVANONE 3-HYDROXYLASE; F3'H, FLAVONOID 3-HYDROXYLASE; DFR, FLS, FLAVONOL SYNTHASE; DIHYDROFLAVONOL REDUCTASE; LDOX, LEUCOANTHOCYANIDIN DIOXYGENASE; PAL, PHENYLALNINE AMMONIA LYASE; CA4H, CINNAMIC ACID 4-HYDROXYLASE; 4CL, 4-COUMARATE-CoA LIGASE; STR, STRICTOSIDINE SYNTHASE.

3. Influence of Light Stress on Medicinally Active Compounds

3.1. Treatment of different plants against light stress

There are vast varieties of work conducted on plants related to light stress among which some of them are discussed in this sub-section. Seedlings of *Sorghum* sp. were treated with high light stress in which the plants are continuously exposed on light intensity of 710 µmol m^{-2} s^{-1} PAR that showed chlorophyll content and Fv/Fm ratios (ratio of variable to maximum florescence) of most varieties of *Sorghum* were declined under high light conditions (Jagtap *et al*., 1998). 25 min at different photosynthetic photon flux density (PPFD) up to 2000 µ mol m^{-2} s^{-1} (Lichtenthaler and Burkart, 1999). After 6h of high light treatment, assimilation rate of irrigated plants increased by 2 to 22% in jowar and by 5% in millets indicating that the C3 cycle was fully functional (Masojldek *et al*., 1991).

In non-stressed leaves of higher plants, Fv/Fm ratios were close to 0.83 which is typical for healthy leaves (Masojldek *et al*., 1991). The time course of Fv/Fm in non-drought-stressed plants showed a biphasic decrease (with a slight reverse 1-2 h after the start) to a ratio of about 0.6 to 0.7 after 6 h of light stress. In some curves, a slight increase of Fv/Fm appeared at

the end of high light treatment (Masojldek *et al*., 1991). The recovery in moderate light after photoinhibition was very fast and it completed within 24 h (Masojldek *et al*., 1991). *Arabidopsis* plants were exposed under low light (200 µmoles of photons m^{-2} s^{-1}) to excess light (2000 µmoles of photons m^{-2} s^{-1}) for 1 h caused reversible photo-inhibition of photosynthesis as decline in the maximum photochemical efficiency of photosynthesis (Karpinski *et al*., 1997). Effect of light irradiation at different periods on *Artimisia annua* L. supplied by fluorescent lamps showed that growth of hairy roots were slowest in the range of light irradiation and increased significantly when intensity of light was increased from 0 to 3000 Lux (Liu *et al*., 2002). The growth of root was similar at 3000 Lux and 4000 Lux (Liu *et al*., 2002). Sufficient light intensity for growth was above 3000 Lux and after 30 days dry weight reached to 13.4 g L^{-1} (Liu *et al*., 2002). Different spectrum of lights also affected plant development at various stages. Increase and decrease in medicinal compounds of several plants against different light exposure is summarized in Table 3. Ultraviolet radiation is also a spectrum of light that has various beneficial and harmful impact on plants that's why functions as stress. According to previous reports, various experiments have been performed with specific wavelength of UV light including UV-A (320-400nm), UV-B (280-320nm), and UV-C (100-280nm). Ultraviolet light also induced the genes that involves in signaling and induction of enzymes (CHS, CHI, FLS, 4CL, STR) responsible for production of secondary metabolites such as anthocyanin, flavonoids, and alkaloids (Fig. 1).

3.2. Influence on anthocyanin

Anthocyanins are water soluble pigments found in all plant tissues throughout the plant kingdom and produced in plants at specific developmental stages but also may be induced by a number environmental stress including visible and UV radiation, temperature, and water stress. Most reports showed the induction of anthocyanin biosynthesis in UV, visible and far-red regions (Beckwith *et al*., 2004). Flavonoids also have several human health benefits as they are utilized as antiviral, anti-allergic, anti-stress, and involves in reduction of blood cholesterol, risk of coronary heart diseases, and platelet aggregation (Kumari and Prasad, 2013). Importance of light stimulus in anthocyanin production is proved by the dark inhibition of anthocyanin synthesis (Beckwith *et al*., 2004). Anthocyanin production in vegetative tissues is related to reducing the oxidative stress under high light conditions (Beckwith *et al*., 2004). According to Zhang *et al*. (2002), biosynthesis of anthocyanin has been found stimulated in the cell suspension of *Vitis vinifera* at high level of light irradiation. As the initial lag phase passes out until day 3, anthocyanin content increased rapidly and reached a maximum value of 6.8 CV/g-FCW (CV; anthocyanin content denoted as color value=0.1 × Absorbance × Dilution factor i.e., CV/g-FCW; fresh cell weight) at day 10 of the culture cycle under continuous irradiation of 8000 Lux (Zhang *et al*., 2002). On the other hand, it decreased from 2.64 to approximately 1.5 CV/g-FCW until day 3 and remained constant up to day 17 in cultures under darkness. As a result, it increased under continuous light irradiation. A maximum of 2.7-fold increase in anthocyanin production was noticed in light- treated cultures (1037 CV/1; color value / litre) compared with dark-treated cultures (388 CV/l) (Zhang *et al*., 2002). According to an early report, UV and far-red light induces independent action of plant anthocyanin photoreceptor in *Rumex patientia* (Scott, 1999). Under supplemental UV-B treatment, anthocyanain content was increased significantly showing higher content in roots (96.3%) as compared to the leaves (32.0%) of *Coleus forskohlii* at 90 DAT (days after transplantation) (Takshak and Agrawal, 2015a). Subsequent studies in which wavelength and photoreceptor are involved in anthocyanin synthesis divides researchers into two groups; the one who supported that anthocyanin synthesis is induced by UV-B photoreceptors, and according to the other one said that it is induced by combination of UV-B photoreceptor, phytochrome and cryptochrome (Scott, 1999). An exclusion experiment of UV-B showed that decrease in anthocyanin content of red-leafed lettuce (Scott, 1999). Anthocyanin significantly changed the quantity and quality of incident light on chloroplasts. Anthocyanin showed higher absorbance of green and UV light and also some amount of red light and lower absorbance of blue light (Steyn *et al*., 2002). Anthocyanin absorbs the blue-green light available to the chlorophyll and their absorption is proportional to the concentration of the anthocyanin (Steyn *et al*., 2002). In addition to a functional role in absorbing light energy, it also played a protective role as antioxidants and it has four times greater antioxidant capacity than α- tocopherol and ascorbic acid (Hughes *et al*., 2005). In a study of high light stress, *Galax urceolata* showed reddening of leaves in substantially more light than the leaves which remained green under low light (Hughes *et al*., 2005).

3.3. Influence on flavonoids

These compounds are ubiquitous in nature and best known for the characteristic red, blue, and purple anthocyanin pigments of plant tissues (Shirley, 2002). They also play essential roles in recruiting pollinators and in seed dispersals (Shirley, 2002). They impart different attractive colors to plant parts and involved in protecting plants against photo-oxidative damage (Shirley, 2002). They are the classical UV-B compounds, and two key enzymes phenylalanine ammonia lyase (PAL) and chalcone synthase (CHS) play important role in the formation of flavonoids which induced under UV-B (Shirley, 2002). The UV absorbing capacity proves its involvement in UV protection. Flavonol the most ancient flavonoid which shows its presence in even mosses and ferns previously considered for taxonomical classifications (Shirley, 2002). As flavonoids are inducible under UV, they show their presence in epidermal layers and tissues susceptible to UV-B (Shirley, 2002). Flavonoids are also major components of herbal and insect preparation for medicines as for example in Propolis (bee's glue) and in honey that had been used since ancient times (Havsteen, 2002). New evidence indicates that polar transport of auxin is also regulated by flavonoids (Shirley, 2002). Flavonoid is a cumulative term for plant pigments derived from benzo-y-pyrone that shows similarity with chromone. High light and UV induce the formation of flavonoid in *Arabidopsis* (Xing *et al*., 2014) as shown in Figure 1.

In light grown cell suspension cultures of *Artemisia absinthium,* a decrease in flavonoid accumulation was found

(Ali and Abassi, 2014). Effect of different light intensity and spectral quality [four different light intensity and spectral quality regimes (i) 30% sun; (ii) 30% sun-UV; (iii) 85% sun; and (iv) 85% sun-UV] on the accumulation of ortho-dihydoxylated flavonoids in *Phyllirea latifolia* L., *Myrtus communis* L. and *Lingustrum vulgare* L. showed that FLAV index increased continuously as light irradiance increased (Agatia *et al.,* 2011). It has been shown FLAV index (flavonoid content) was 9%, 33%, or 66% greater in 30% sun, 85% sun-UV and 85% sun treatments, respectively, than in the 30% sun-UV treatment (Agatia *et al.,* 2011). Secondly, has also been suggested that exclusion of UV in 85% sun reduced the FLAV index by 20% while sunlight shading comparing with 85% sun-UV and 30% sun-UV reduced the FLAV index to a higher extent (approx 33%) (Agatia *et al.,* 2011). There are several reports which showed that exposure of UV and blue light induces the phenylpropanoids biosynthesis which provides further protection to the photosynthetic apparatus from photo-oxidative damage, despite an initial decline in photosynthetic performance (Guidia *et al.,* 2016). Flavonoids serve a number of functions in photo-protection: they efficiently absorb short-wave solar radiation, thus decreasing the risk of photo-oxidative stress in plants, as well as countering photo-oxidative damage by scavenging free radicals and reactive oxygen species, such as singlet oxygen ($^1O_2$) and hydrogen peroxide (Guidia *et al.,* 2016). In response to high solar radiation, flavonoids accumulation occurs, not only restricted to epidermal region but also extended to mesophyll regions of leaf (Guidia *et al.,* 2016). High sunlight almost exclusively induces the biosynthesis of flavonoids with the greatest antioxidant capacity, in the presence or in the absence of UV-irradiance (Guidia *et al.,* 2016). The induction (maximum by 53%) and accumulation of flavonoid occurs under sUV-B dose of +3.6 kJ m^{-2} d^{-1} above ambient UV-B in *Cymbopogon citratus* (Kumari and Agrawal, 2010). In another study of Kumari *et al.* (2009), flavonoid content was found to be increased by 67.6% under sUV-B (+1.8 kJ m^{-2} d^{-1} above ambient), while 39.4% under sUV-B (+3.6 kJ m^{-2} d^{-1} above ambient) in leaves of *Acorus calamus* L. (Sweet Flag). A recent findings led to a hypothesis that excess light stress irrespective of specific solar wavelength bands, reaching the leaf surface up-regulates the genes of antoxidant flavonols, FLS (flavonol synthase) and F3'H (flavonoid 3'-hydroxylase) and UV irradiance also induces the formation of dihydroxy B-ring-substituted flavonoid glycosides (i.e., the antioxidant flavonoid structures usually encountered in leaf tissues) in *Ligustrum vulgare* leaves (Fini *et al.,* 2011). FLS and F3'H enzymes are involved in the induction of flavonoid biosynthesis that might be able to counteract the excess generation of reactive oxygen species (ROS) (Fini *et al.,* 2011). It has also been suggested that flavonoids are increased under adverse light conditions and behave as antioxidants in photo-protection (Fini *et al.,* 2011).

3.4. Influence on alkaloids

Alkaloids are low molecular weight nitrogen-containing heterocyclic organic compounds and present in 20% of all plant species. The numbers of identified structures of alkaloids have been 12,000 or more than 16,000 (Zhang and Björn, 2009).Well known alkaloids include morphine, strychnine, quinine, ephedrine, and nicotine. Alkaloids are important secondary metabolites and interest in alkaloids has been increasing continuously as their pronounced medical significance in human health care. But there are several plant secondary metabolites such as, ephedrine from *Ephedra sinica*, colchicines from *Colchicum autummale*, with non-heterocyclic rings are also included under alkaloid category (Schlager and Drager, 2016). Alkaloids have a very strong pharmacological effect (Schlager and Drager 2016). Alkaloids have very strong pharmacological effect (Schlager and Drager 2016). The plant species that contain desired alkaloids showed variation in growth and alkaloid contents (Schlager and Drager 2016). Alkaloids can be classified on the basis of chemical structures, pointing first at the alkaloid base, a basic chemical nucleus (Aniszewski, 2015). The basic types of alkaloids are: acridones, aromatics, carbolines, ephedras, ergots, imidazoles, indoles, oxindoles, bisindoles, indolizidines, manzamines, quinolines, quinozolines, quinolizidines, phenylisoquinoles, phenylethylamines, piperidines, purines, pyrolidines, pyrrolizidines, pyrroloindoles, pyrydines, sesquiterpines, simple tetrahydoquinolines, stereoides, tropanes, terpenoids, diterpines, and triterpenes (Aniszewski, 2015). In a study, cultures of *Coffea arabica* was exposed to high light intensity (400 ~µmol m^{-2} sec^{-1}), large aggregates of culture showed alkaloid content (analyzed by data processing HPLC system) 154±28 (mean of six cultures analyzed three at time ± standard error of the mean) under light stress as compare to control i.e., 45±05 while in small aggregates it was 329±09 in light treatments and 93±13 in control condition (Frischknecht and Baijmann, 1985). In an experiment, *Camphotheca acuminata* Decne seedlings were exposed to different light qualities by using white, blue, yellow, and red plastic filters (Liua *et al.,* 2015). Camptothecin content increased more in blue light treatment and less in yellow light at 30 DAT (days after treatment) but it was high in blue light treatment than in yellow light at 30 DAT and very slight increase was noticed in red light (Liua *et al.,* 2015) (Fig. 2). At 45 DAT, increment in camptothecin content was highest in blue light than yellow light and slightly increased in red light but very little increase in white light have been observed (Liua *et al.,* 2015). In a previous study of Ramani and Jayabaskaran (2008), in cell suspension culture of leaves of *Catharanthus roseus*, concentration of catharanthine and vindoline was found to be increased under sUV-B treatment and it was highest at 48 to 72 h after UV-B irradiation.

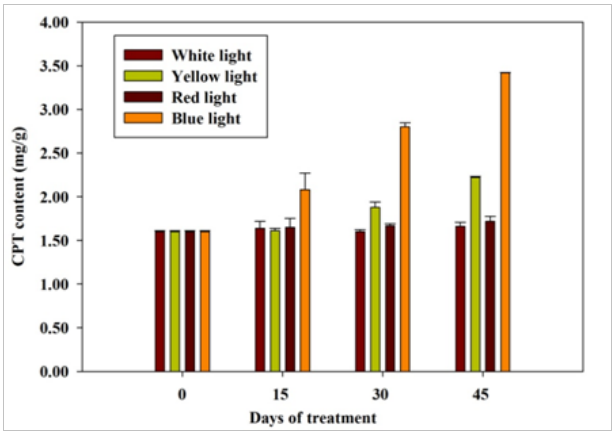

Fig. 2: Effect of spectral light quality on camptothecin content in *C. accuminata* Decne seedlings.

Table 3: Influence of light conditions on increase and decrease of secondary metabolite production in different plant species.

Secondary metabolite	Plant species	Light condition	Effects	Reference
Anthocyanin	*Vitis vinifera*	Light irradiation (8000 Lux)	2.7 fold increase	Zhang *et al*. (2002)
	Coleus forskohlii	Supplemental UV-B	Increase Leaves (27.98%) Roots (96.32%)	Takshak and Agrawal (2015a)
	Rumex patientia	Far-red light	Increase	Scott (1999)
	Galax urceolata	High light	10 fold increase	Hughes *et al*. (2005)
Flavonoids	*Artemisia absinthium*	Light (grown suspension culture)	Increase Log phase (87%) Stationary phase (80%)	Ali and Abbasi (2014)
	Phyllirea latifolia L. *Myrtus communis* L. *Lingustrum vulgare* L.	High light irradiance (Sun+UV)	Increase (18%) From 30% sun+UV to 85% sun+UV	Agatia *et al*. (2011)
	Ligustrum vulgare	UV irradiance	Increase (100%) in presence of 100% sunlight irradiance	Finni *et al*. (2011)
	Cymbopogon citratus	Supplemental UV-B (+3.6kJ m^{-2} d^{-1})	Increase (53%)	Kumari and Agrawal (2010)
	Acorus calamus	Supplemental UV-B (+1.8 kJ m^{-2} d^{-1} and +3.6kJ m^{-2} d^{-1})	Increase (67.6% and 39.4%)	Kumari *et al*. (2009)
Alkaloids	*Coffea arabica*	High light Intensity (400 ~µmol/m^{-2} sec^{-1})	Increase Large aggregates 242% Small aggregates 253%	Frischknecht and Baijmann (1985)
	Camphotheca acuminate	Blue light Yellow light Red light	Increase In Blue 116%, Yellow 50%, Red light approx 16%	Liua *et al.* (2015)
	Coleus forskohli	Supplemental UV-B	Increase Leaves 125.8% Roots 153.9%	Takshak and Agrawal (2015a)
	Withania somnifera	Supplemental UV-B	Increase in withaferin A (160%) Decrease in withanolide (41.2%)	Takshak and Agrawal (2014)
	Psychotria brachyceras	Supplemental UV-B	Increase (100%)	Kumari and Prasad (2013)
	Potato peels	Pulsed pre-light	Increase Alpha solanine (38.78%), Alpha chaconine (33.13%)	Hossain *et al*. (2015)
Essential oils	*Mentha sps.*	Red light Blue light White light Sunlight	More increase in under red light (39% and 86% than blue and white light respectively) Lowest increase under sunlight	Dou *et al*. (2017)
	M. arvensis	Red light Blue light Green light	Increase more in red light (1.4 times higher) than blue and green light	Dou *et al*. (2017)
	Glycyrrhiza uralensis	Red light White light Blue light	More increase under red light than white and blue light	Dou *et al.* (2017)
	Ocimum basilicum	Blue light White light Red light	More increase under blue and red light than white light	Dou *et al.* (2017)

	Cymbopogon flexuosus	Red light	Increase (30%)	Prins *et al.* (2013)
	Cymbopogon citratus	Light (1210 µmol m^{-2} s^{-1} on average)	Increase (285%)	Prins *et al.* (2013)
	Coleus forskohlii	Supplemental UV-B	Decrease (7%)	Takshak and Agrawal (2015b)
	Matricaria chamomilla	White light (about 1.5 x 103 ergs/cm^2 sec) for 18 h	Increase at 18h daylength than 14 h and 24 h	Saleh (1968)
Cannabinoids	*Cannabis sativa*	UV light	Increased	Zhang and Björn (2009)
	Brassica oleracea	High light and high temperature	Increase	Rosa and Rodrigues (1998)
Glucosinolates	*Brassica napus*	Far-red light	Increase	Carvalho and Folta (2014)

The enhanced production of catharanthine in cell- suspension culures of *C. roseus* occurs through signaling induced by UV-B, which includes receptor activation, medium alkalinization (Ca^{2+} influx and Cl^- efflux), ROS (reactive oxygen species) production, MAP kinase pathway activation that led to *Tdc/Str* gene (genes encoding tryptophan decarboxylase and stricosidine synthase) expression responsible for cathranthine production (Ramani and Chelliah, 2007) . Alkaloid contents in both leaves and roots of *Coleus forskohlii* were increased under supplemental sUV-B (+3.6 kJ m^{-2} d^{-1} above ambient) treatment. The increase was highest in leaves at 90 DAT (125.8%) and 60 DAT in roots (153.9%) (Takshak and Agrawal, 2015a). Under the sUV-B (+3.6 kJ m^{-2} d^{-1} above ambient 9.6 kJ m^{-2} d^{-1}) *Withania somnifera* showed increase of 160.1% alkaloid withaferin A in young leaves but it was reduced by 43.3% and 2.3% in middle and old leaves, respectively while withanolide A showed an overall decrease of 41.2% in leaves (Takshak and Agrawal, 2014). The data suggests overall increase of 12.4% in alkaloid content in above ground parts, however, 2-3 fold increase in basal and middle roots and decrease of 54.8% in withaferin A in root tips have also been observed (Takshak and Agrawal, 2014). A monoterpene indole alkaloid brachycerine obtained from *Psychotria brachyceras* was almost doubled under sUV-B exposure (Kumari and Prasad, 2013). Pulsed pre-light treatments (PL) were applied on the potato peels for the determination of steroidal alkaloids (Hossain *et al.,* 2015). It consists of a controller unit and a treatment chamber that houses a Xenon flash lamp capable of delivering high intensity white light in short pulses (Hossain *et al.,* 2015). Pulsed light is used for microbial inactivation, but application on living cells (as light stress particularly in the UV region) triggered biosynthesis of defense related compounds such as steroidal alkaloids (Hossain *et al.,* 2015). The results showed an increase in the content of steroidal alkaloids, alpha-solanine (69.85 µg g^{-1} Dry weight) and alpha-chaconine (189.36 µg g^{-1} DW) (Hossain *et al.,* 2015).

3.5. Influence on essential oils

Essential oils are a kind of natural oils obtained from medicinal plants with the help of extraction and distillation technique. They are a mixture of volatile and non-volatile compounds and mostly soluble in ethanol (Trujillo *et al.,* 2015). Since ancient age, they have been used for their insecticidal, medicinal and cosmetic purpose and their detailed effects have been explained by Bakkali *et al.* (2008). Some essential oil compounds are terpenoids (a class hydrocarbons and derivatives of them) (Zhang and Björn, 2009). The essential oil producing families are not restricted to a specific taxonomic group as they are diverse across the plant kingdom covering a large number of families from gramineae to rosaceae (Sangwan *et al.,* 2001). The constituent of plant essential oil comes under two entirely distinct chemical classes, terpenoids and, phenylpropanoids (Sangwan *et al.,* 2001). Although terpenes represent the major components, occurring much more frequently and abundantly, while phenylpropanoids provide essential and significant flavour and odour to the oil (Sangwan *et al.,* 2001). Red, blue and UV light enhanced the production of essential oil as compared to white light or sunlight, this enhancement may be varied among species, compounds and light treatments (Dou *et al.,* 2017). According to Sabzalian et al. (2014), the total essential oil content of *Mentha piperita, M. spicata*, and *M. longifolia* was highest under red light at 500 µmol m^{-2} s^{-1} PPF (photosynthetic photon flux) and 16-h photoperiod for 60 days, 39% and 86% higher than blue or white light, respectively, and was lowest under sunlight. In *M. arvensis*, l-menthol, the main component of essential oils was 1.4 times higher under red light than blue or green light, both at 150 µmol m^{-2} s^{-1} PPF and 16-h photoperiod for 28 days (Nishioka *et. al.,* 2008; Dou *et al.,* 2017).

Glycyrrhizic acid (an oleanane-type triterpenoid saponin and considered to be 50 times sweeter than sugar) concentration in root tissues of Chinese liquorice was highest under red light, followed by white light, and lowest under blue light at 300 µmol m^{-2} s^{-1} PPF and 16-h photoperiod for three months (Dou *et al.,* 2017). Although enhanced UV light generally inhibits plant growth, it might increase essential oils, resulting in enhanced plant defense and protection against UV light (Dou *et al.,* 2017). According to Kumari *et al.* (2009), exposure of sUV-B (dose of +1.8 kJ m^{-2} above ambient) on *Cymbopogon citratus* showed an increase in frequency of oil cells by 41.19% while essential oil content was increased by 25.71% on fresh weight basis (v/w) as compared to control plants. It was also observed that z-citral which is the major component of essential oil of *C. citratus* was found to be increased by 70% in sUV-B treated plants (Kumari *et al.,* 2009). As documented by Takshak and Agrawal (2015b), sUV-B reduced the essential oil content in *Coleus forskohlii*. UV-B or combination of UV-A and UV-B light with white light was more effective than white light alone in increasing l-menthol and limonene concentrations in *M. arvensis* as well as the content of essential oils in Chinese liquorice, such as glycyrrhizic acid, liquiritin, liquiritigenin, and isoliquiritigeni (Dou *et al.,* 2017). In sweet basil, the total

essential oils under blue light were 1.2 - 4.4 times higher than plants grown under white light, and was lowest under red light at 50 µmol m^{-2} s^{-1} PPF and 16-h photoperiod for 70 days (Dou *et al.,* 2017). In light-shade treatment with *Myrtus communis*, essential oil yield ranged from 0.48 to 0.93 % in the shaded site (Fadil *et al.,* 2016). It showed a small increase in essential oil yield in light-exposed plants which varied between 0.88 and 1.06 % (Fadil *et al.,* 2016). In Figure 3, a cumulative value of % essential oil of 10 plants exposed to light and shade are provided.

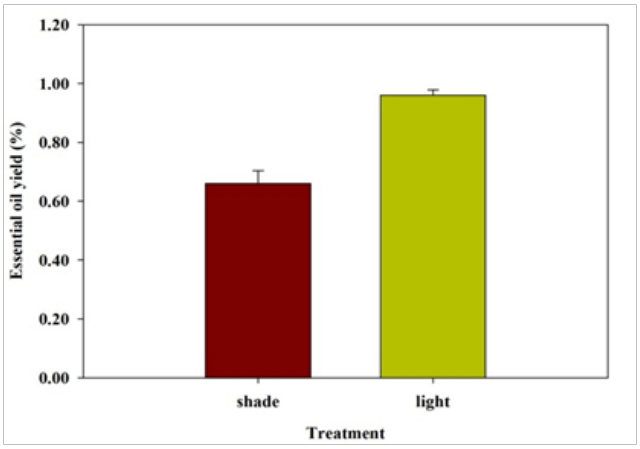

Fig. 3: Change in percentage of essential oil content in *M. communis* under shade and light conditions.

Light availability and quality can be positively correlated with essential oil production, as observed with *Cymbopogon flexuosus*, which showed an increase of approximately 30% in essential oil biosynthesis when plants were treated with red light (Prins *et al.,* 2013). Experiment with *C. citratus* (lemongrass) treated with light (1210 µmol m^{-2} s^{-1} on average) and shade treatment (183 µmol m^{-2} s^{-1} on average) showed that the average percentage of essential oil (citral) was 1.08%, but the content of essential oil (g $plant^{-1}$) was higher in plants grown under light conditions (Prins *et al.,* 2013). The trend indicated a favorable effect of light for essential oil production. There was no effect of light intensity on essential oil content, while essential oil yield was higher in plants grown at the full light as a result of increased biomass (Prins *et al.,* 2013). An experiment on *Matricaria chamomilla* L. was conducted in which normal day length of plant was increased with different durations of white light (6, 8 or 16 hours) with an intensity of about 1.5×10^3 ergs/cm^2 sec (Saleh, 1968). The results of the experiment showed that volatile oil per plant was highest at 18 hours day length, followed by 24 and 14 hours day length, respectively (Saleh, 1968). Carvalho *et al*. (2016), studied light quality dependent changes in *Ocimum basilicum* (sweet basil) and showed phenylpropanoids are more abundantly formed followed by sesquiterpenoids and monoterpenoids. Hence, light quality could be manipulated to enhance targeted compound concentrations for various purposes.

3.6. Influence on cannabinoids

Cannabinoids are class of chemical compounds produced by *Cannabis sativa* L. According to a previous study, leaves from plants grown under filtered green light and darkness contained significantly lower levels of A'-THC (Δ^9-tetrahydrocannabinol) than those from plants grown in daylight (Mahlberg and Hemphill, 1983). The cannabichromene (CBC) content of plants grown under filtered red and green light and darkness differed from the CBC content in plants grown in daylight, indicating that the formation of this cannabinoid was independent of A'-THC (Mahlberg and Hemphill, 1983). Plants from all light and dark treatments, when subsequently placed under daylight conditions for 66 days, attained higher levels of cannabinoid synthesis as compared to the daylight controls (Mahlberg and Hemphill, 1983). According to Pate (1983), UV-B radiation enhanced cannabinoid production in *Cannabis* and also speculated about cannabinoid evolution (Zhang and Björn, 2009). UV-B exposure in different growth organs of plant showed an increase in Δ9-tetrahydrocannabinol (Δ9-THC) with exposure, but a decrease was noticed in cannabidiol (Zhang and Björn, 2009).

3.7. Influence on glucosinolates

Brassicaceae family includes all the crucifer vegetables such as cabbage, broccoli, cauliflower, kale, etc. are some of the most popular vegetables consumed over the world and contains a good source of phytochemicals (Variyar *et al.,* 2014). Glucosinolates (GSLs) are sulphur containing chemical compounds responsible for the characteristic flavor and odor of Brassicaceae members (Variyar *et al.,* 2014). They are class of secondary metabolites generally limited to family brassicaceae (Variyar *et al.*, 2014). Hydrolysis products of GSLs have biological activities such as defense compounds and attractants, besides, it also works as cancer preventing agents, flavoring agents, biofumigants, and biopesticides (Halkier and Gershenzon, 2006). There are 120 described glucosinolates share a chemical structure of β-D-glucopyranose residue liked via a sulphur atom to a (Z)-*N*-hydroxyminosulphate ester and a variable R-group (Halkier and Gershenzon, 2006). According to earlier reports as documented by Variyar *et al.* (2014) environmental factors, such as light, temperature, salinity, and drought may affect GSLs levels. In a study, light treatment applied on cabbage plants on two different temperatures showed that levels of total GSLs were significantly higher in roots than leaves (Rosa and Rodrigues, 1998). When compared at 20ºC and 30ºC temperature, no significant increase in leaves was noticed but GSLs were higher in roots at 30º C as compared to 20ºC (Rosa and Rodrigues, 1998). As documented by Kumari and Prasad (2013), Arabidopsis leaves induced the glucosinolates production under 1h of UV-B (1.5 Wm^{-2}) exposure while its production reduced over continuous exposure of 12 h. According to a previous study in summer season, conditions (when light and temperature was high) were more favourable for high level of GSLs production than winter (Rosa and Rodrigues, 1998). The wavelength of 470, 660, 730 nm along with white light supplied by Philips Cool White Fluorescent Bulbs (Newark, NJ) applied on shape kale (*Brassica napus*) showed that total GSLs level was highest in far-red light with approximately 15-42% accumulation compared to other light treatments (Carvalho and Folta, 2014).

4. Conclusion

It is clear from previous studies that the contents of medicinal compounds in plants are modulated under exposure to

light which includes blue, red and UV light in which UV-B light was found to be most effective. Specific wavelength and intensity of light may be required to increase specific medicinal compounds. Thus, in order to make higher production of medicinally important compounds, it may be advisable to apply different wavelength of light for different durations depending upon species of medicinal plant.

Acknowledgements

The authors are thankful to the Head, Department of Botany and Coordinator, Centre of Advanced Study (CAS) in Botany, Banaras Hindu University, for providing library and internet facilities. Deepanshi Jaiswal is also grateful to the University Grants Commission (UGC), New Delhi, for providing financial support in form of UGC-JRF.

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