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RESEARCH ARTICLE

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PLANT SECONDARY METABOLITES AND CLIMATE CHANGE

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ABSTRACT

Plant secondary metabolites (PSMs) are plant products that are variously distributed throughout the plant kingdom. These secondary compounds have various chemical groups and are named according to their chemical constituents. For their ability to defend biotic and abiotic stresses they are considered as plants' defensive or bio-functional compounds. These metabolites derived from secondary metabolism of plants are produced for protection of the species from insects, herbivores and extreme environmental conditions. They are indirectly involved in plants' growth and development. Secondary metabolites are also used by people in the form of medicines, pharmaceuticals, agrochemicals, colors, fragrances, flavorings, food additives, biopesticides, and drugs development. Different ecologically limiting factors including temperature, carbon dioxide, lighting, ozone, soil water, soil salinity and soil fertility has significant impact on plants' physiological and biochemical responses, as well as the secondary metabolic process. Secondary metabolites are the key players in plant adaptation to these environmental stresses and play a role in mitigating the negative effects of these stresses. Both primary and secondary metabolisms are altered under these stress environments, however, plants have evolved to endure these conditions through inducing several regulating mechanisms including induction of antioxidant machinery and fine tuning of transcriptional and post-transcriptional regulations of gene expressions. In most of the plants, the ultimate result of these changes. The review showed the influence of different environmental variables on SMs production and accumulation is complex suggesting the relationship are not only species-specific but also related to increases and decline in SMs.

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INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC), mean annual temperature is increasing faster to a rate of 0.06 –0.1 °C/yr. with a CO2 increase of 407.4 parts per million [1]. Change in climatic conditions not only influences the normal behaviors of plants but also their physiology, ultimately affecting the secondary metabolites. Due to rapid climate change, plants have become increasingly exposed to novel environmental conditions that are outside of their physiological limits and beyond the range to which they are adapted. Extreme temperature, environmental factors and abiotic stresses are some of the conditions that are compounded by climate change. This condition will lead to a variety of positive and negative effects on major agricultural crops. Along with changes in photosynthesis and biomass production, metabolic changes are considered to be one of the early reactions of plants toward climate change conditions. Secondary metabolism is postulated as one of the mechanisms plants use in the quest to interact with and adapt to their dynamic environments. Environmental stresses include drought, salinity, extreme temperatures, toxic gases,ozone, carbon dioxide, and other wastes released into environment because of climatic aberrations [2]. Plants being sessile organisms face several environmentalperturbations during their life cycles [3]. These environmental signals induce several changes in plants at physiological, biochemical and molecular levels [4]. Both primary and secondary metabolisms get affected under change in environment or climate, however, plants have evolved to sustain under these conditions via inducing several counter-balancing mechanisms such as regulated use and evapo-transpiration of available water, controlled openings and closings of stomata as per the availability of water, overaccumulation of various osmo-protectants and osmo-regulators, induction of antioxidant machinery and fine tuning of transcriptional and post-transcriptional regulations of gene expressions [5]. However, there is lack of substantial data and in-depth understanding about the impacts of toxic gases, greenhouse gases and ozone on plant secondary metabolism as a whole and on the production of plant secondary metabolites (PSMs). Nevertheless, there is a recent upsurge on the significance of altered plant secondary metabolism and enhanced production of PSMs under the influence of these gases as well as other wastes including the nanoparticles-wastes released into the environment. It could be summarized that secondary metabolites are a vital part of the reaction network of plants toward the changing climate and their production is mostly stimulated, but this tendency needs to be carefully interpreted. This chapter deals with all these issues of plant regarding Climate change.

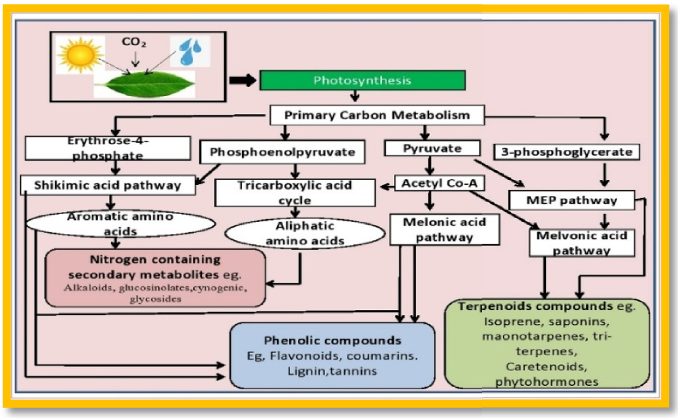

Figure 1. Secondary metabolites from Plants

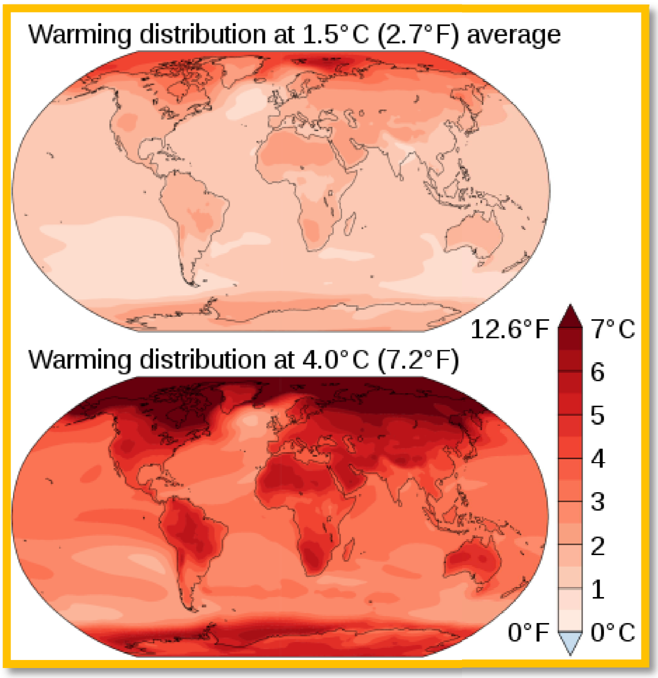

Figure 2. Average IPCC AR5 climate model projections for 2081–2100 relative to 1986–2005, under low and high emission scenarios

Response of Plant to changing Climatic condition: Plants are good sources of chemical substances like terpenoids, phenols, steroids, flavonoids, tannins and aromatic compounds which are widely used in the pharmaceutical, cosmetics and food industry. These chemical substances are commonly known as secondary plant metabolites which are not essential for the growth and development of the plant but are considered as defense compound to interact with its environment for adaptation [6]. There are over 2,140,000 secondary metabolites and are divided into different groups consisting of 29,000 terpenoids, 12,000 alkaloids, 8,000 phenolics, steroids, flavonoids, tannins, and more are in the process of identification [7]. Studies showed that some environmental factors like temperature, elevated CO2, Ozone, UV light, drought adversely affects the metabolites, growth and productivity in plants. These secondary metabolites (SMs) exhibit significant changes in their synthesis and accumulation to the abiotic stress and hence their economic value and yield also get affected.

Temperature Stress: Change in temperature affects plant growth and metabolic pathways involved in signaling, physiological regulation and defense responses. [8,9] Temperature as major weather variables can significantly influence the composition of SMs with disruption in photosynthesis activities to tolerate stressful condition. For example, vegetative development (node and leaf appearance rate) increases as temperature rise to species optimum level while cold temperature limit plant growth, leaf development and photosynthesis. The area where the species is cultivated can be modified according to the range in temperature change especially in their reproductive cycle. For instance, the composition of alkaloids in *Duboisia myoporoides* demonstrated a minor increase with temperature (4°C) [10], Zhang et al.[11] indicated an increase in tanshinones accumulation in *Salvia miltiorrhiza* with an increase in temperature. In *Tithonia diversifolia* there is an increase in phenolic compounds at 22°C and a decrease afterwards[12]. *Camellia japonica* global gene regulation of unsaturated fatty acid and jasmonic biosynthesis pathways were deduced in the low temperature [13]. On contrary, high temperature reduce silymarin content in *Silybum marianum* roots showing SMs accumulation is a temperature-dependent process [14]. *Dendrobium officinale* results showed higher levels of polysaccharide, total alkaloid and total flavonoid content in response to increase in temperature. *Withania somnifera*, the ashwagandha showed in an increase in key bioactive compound steroidal lactones; withanolide accumulation in foliage to cold stress response [15]. They found metabolites content decrease with the increase in temperature indicating it is a shade lover and too high temperature is detrimental for growth. This shows the influence of temperature on plant growth and SMs synthesis is not univocal indicating species-specific effects (Table 1).

CO_2 Stress : Carbon dioxide is considered a major greenhouse gas hampering the physiology of medicinal plants. Since the industrial revolution, the concentration of it is increasing rapidly from 270 parts per million (ppm) to 407.4 ppm [16]. Plant adapts to change in environment through metabolic plasticity, however, this affects the SMs which are the basis for their medicinal activity [17]. *Hypericum perforatum* known for its use in moderate depression was treated with elevated CO_2 and found growth to be increased after 140 days compared to ambient conditions. In the same experiment, hypericin concentration significantly decreases by 22% in elevated CO_2. A study on *Centella asiatica*, used as medicinal herbs for its multiple therapeutic properties showed improved photosynthetic efficiency initially with a higher concentration of flavonoids under elevated CO_2 levels. Furthermore, there was an increase in flavonoids concentration in the irradiated plants with rising CO_2 concentration from 400 to 800 µmol/mol [18]. In *Stevia rebaudiana*, elevated CO_2 increased Steviol glycosides content, a low-calorie sweetener [19]. It was observed that elevated CO_2 enhanced photosynthetic rate and water use efficiency thereby reducing the threat of oxidative stress. A similar study conducted on *Mentha piperita* showed an increase in flavonoids concentration with the application of elevated CO_2 of 360 ppm and 620 ppm [20]. In a typical study on *Hibiscus sabdariffa* elevated CO_2 levels from 400 to 800 µmol/mol showed an increase in calyx yields and total phenol concentration [21]. Moreover, it is also predicted that an increase in CO_2 may result in greater height and higher fresh yields than ambient CO_2. Kaundal *et al*. [22]. subjected *Valeriana jatamansi* to elevated CO_2 levels (550 µmol/mol) and exhibited increased essential oil production. *In vitro* study performed with Brazilian ginseng showed increased phytoecdysteroid 20- hydroxyecdysone under CO_2 enrichment (1000 µL/ CO_2L), this study was important in demonstrating the best culture conditions and increasing the development and production of 20-hydroxyecdysone in the species [23]. The overall trend in such finding showed the importance of secondary metabolites of medicinal plants with respects to CO_2 besides seasonal variation, time duration and nutrient availability. This can provide insight into the role of elevated CO_2 in altering the metabolic plasticity of medicinal plants providing appropriate conservatory practices in the long run.

Ozone Stress : Ozone is considered as a bio protector from ultraviolet radiations, however, at ground level, they affect both animals [24] and plants. *Hypericum perforatum* showed an increment of total phenols and flavonoids (quercetin) with activation of peroxidase activity by ozone (110 ppb, 5 hrs.) confirming that ozone is an elicitor of bioactive secondary metabolites [25]. Similarly, at 24 h of exposure (110 ppb), the increase of quercetin was replaced by a raise of Kaempferol (another flavonol) while isoquercitrin and quercitrin remain unchanged. This suggests that ozone treatment can be considered to enhance the concentration of antioxidants phytochemical increasing the beneficial properties of medicinal plants.

Table 1. Effects of Environmental Factors on plant secondary metabolite production

Plant	Secondary Metabolites	Environment Factor
Arabidopsis thaliana (L.) Heynh	Glucosinolates	Elevated Co_2
Betula pendula	Dehydrosalidroside hyperoside, Betuloside	Elevated O_3
Brassica napus L.	Phenols, Tannins	Salinity stress
Camellia japonica	Alpha Linolenic acid, Jasmonic acid	Low Temperature
Capscicum baccatum	Capsacin and Dihydrocapsaicin	Elevated 03
Carthamus tinctorius L.	Flavonoids	Salinity stress
Centella asiatica (L.) Urban	Flavonoid	Elevated Co_2
Chrysanthemum morifolium Ramat	Phenols	UV B radiation
Coleus forskohli Briquet	Flavonoids and Phenolics	UV B radiation
Digitalis lanata	Digoxin, Cardenolide	Elevated Co_2
Ginkgo biloba	Tannins, Quercetinaglycon, Keampferolaglycon, Bilobalide	Elevated O_3 and CO_2
Glechoma longituba (N.) Kuprian	Ursolic acid and Oleanolic acid	Light intensity
Glycyrrhiza glabra	Glycyrrhizin	Drought Stress
Hibiscus sabdariffa	Phenol and Flavonoid	Elevated ozone
Hypericum perforatum L.	Hypericin	Elevated Co_2
Hypericum perforatum L.	Phenols and flavonoid	Elevated 0_3
Hyptis marrubioides Epling	Rutin	Light intensity
Mahonia breviracema Wang & Hsiao	alkaloids	Light intensity
Mellisa officinalis	carotenoids	Elevated 03
Mentha piperita	Flavonoids	Elevated Co_2
Papaver setigerum	Morphine,Codeine,Papaverine and Noscapine	Elevated Co_2
Prunella vulgaris L. Spica	Total Flavonoids, Rosmarinic acid, Caffeic acid	UV B radiation
Pseudotsuga manziesii	Monoterpenes	Elevated Co_2
Salvia miltiorrhiza Bunge	Tanshinone	Temperature
Silybum marianum (L.) Gaertn	Silymarin	Temperature
Stevia rebaudiana Bertoni	Steviol Glycosides	Elevated Co_2
Tithonia diversifolia (Hemsl.) A. Gray	Phenols	Temperature
Trigonella foenum-graecum L.	Trigonelline	Salinity stress
Valeriana jatamansi Jones	Essential oil, saponins and Phytosteroids	Elevated Co_2
Withania somnifera L. Dunal	Withanoloide	Elevated Co_2
Zingiber officinale Roscoe	Flavonoids, Phenols	Elevated Co_2

Similarly, a study on eco-physiological and antioxidant traits of Salvia officinalis L. under ozone stress showed an increase in phenolic content; notably Gallic acid (2-fold increase), Caffeic acid (8-fold increase) and Rosmarinic acid [26], A study on *Melissa officinalis*, a traditional medicinal plant with a large number of uses including dementia and anxiety showed an increase in total anthocyanins to a substantial extent along with phenolic and rosmarinic acid in plants subjected to ozone treatment [25]. More studies with wide perspectives and plan are needed for depicting the role of this treatment as enhancer of production of secondary metabolites as well as to understand the role of increased oxidative stress conditions on the conservation and management of cultivated as well as spontaneous medicinal plants.

Ultraviolet Radiation Stress: Ultraviolet (UV) light is also an important abiotic factor that stimulates the production of secondary metabolites. The concentrations of flavonoids and phenolic acids increased in response to increasing UV B radiation of *Chrysanthemum morifolium* [27]. Similarly, a study on *Coleus forskohlii* Takshak and Agrawal [28], showed an increase in flavonoids and phenolic content under UV B stress. When the plant *Prunella vulgaris* was irradiated with UV B, the production of total flavonoids, rosmarinic acid, caffeic acid was enhanced [29]. However, these contents differ in development stages and the best harvest stage was between budding and full-flowering for the best medicinal values. Nascimento *et al.* [30], found that the level of phenolic profile and flavonoids content in *Kalanchoe pinnata* leaves increase in response to UV B irradiation. The content was further increased in the combination of white light providing higher diversity of phenolic compound and a larger amount of quercitrin. These studies highlighted the importance of photoperiod and light intensity for photosynthesis, growth and accumulation of secondary metabolites in medicinal plants. Thus, medicinal properties yield might be achieved by proper adjustment of light quality and quantity in future. ***Soil Stress:*** Soil influences the growth and development of plants, and SMs accumulation is strongly dependent on soil water (drought stress), soil salinity and soil fertility.

Soil Water Stress (Drought Stress) Drought stress is an important environmental factor affecting the content of secondary metabolites in plants. A larger number of studies manifested that plants exposed to drought stress accumulate a higher concentration of secondary metabolites than those cultivated under well-watered conditions [31, 32]. This result demonstrates that an appropriate degree of drought stress may promote alkaloid accumulation by stimulating the expression and activities of the key enzymes involved in the biosynthesis of the compound.

CONCLUSION

Plant secondary metabolites (PSMs) are responsible for protecting plants in adverse environmental conditions. Plant secondary metabolites help the plant kingdom to survive against oxidative stress-mediated damages which causes cell death and damage to cell membranes. PSMs are the first line of defense for the damage control of plants.The role of various greenhouse gases (GHGs) (CO2, CH4, N2O, and O3) is to elicit the atmospheric temperature, on the other hand, e [CO2] and heat stress lead to the generation of a higher number of few secondary metabolites; however, climate change and the warmer environment are harmful it is quite beneficial for the plant kingdom. Several other greenhouse gases (GHGs) also affect plant growth and development as well as their primary productivity. Secondary metabolites help humans to fight against cancer, HIV, brain dysfunction, inflammation, RNA virus-mediated dis- eases, etc. Moreover, many PSMs are the precursors of several important PSMs. In this regard, the production of secondary metabolites is very much important to maintain many socioeconomic purposes. It is evident that climate change influences growth and PSMs production in higher plants. Plant productivity also depends on the changing ecosystem. It is observed that high temperature will increase secondary metabolite production might be helpful to produce transgenic plants with high metabolite yielding capacity and new drugs. Several biotechnological tools are employed for the enhanced production of secondary metabolites. So, a warming environment may lead to the innovation of a new industry and help in economic progress. It will also deplete the environmental food web and the survival of the lower group of plants and animals. Ozone, UV radiations and altered soil conditions also have exhibited various changes in PSMs productions, but further research is necessary to evaluate the mechanism and possible manipulations by changing environmental conditions to benefit the society, plant drug industries and also sustainable crop production.

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