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Review Article

Impact of altitudinal stress on secondary metabolite pool in plants

Rubaya Sultan[1*], Saduf Nissar[2], Neelofar Majid[2] and Aabid M. Rather[2]

[1] Research Laboratory, Department of Botany, University of Kashmir, Srinagar, 190006, J&K, India

[2] Department of Botany, S.P. College Srinagar, 190001, J&K, India

[2] Plant Reproductive Biology, Genetic Diversity and Phytochemistry

*Corresponding Author: Aabid M. Rather

E-mail address: abid.bot@gmail.com

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Abstract

Active substances are the result of the interaction between plants and the environment in the long evolution process, and its production and changes have a strong correlation and association with the environment. Plants are exposed to different biotic and abiotic factors and in response activate their defense systems throughout their life span. Altitude is one of the factors influencing the secondary metabolic pathways in plants. Plants being sessile, have elaborated alternative defense strategies involving the huge variety of secondary metabolites as tools to overcome stress constraints, adapt to the changing environment and survive. This review is an attempt to provide a comprehensive knowledge about altitudinal variation of phytochemicals. Along an altitudinal gradient sampling of populations allows to assess the intraspecific variations and main ecological trends of phytochemical accumulation in plants. So this can facilitate to select elite genotype and reflect the best suited altitude for commercial cultivation of the species as these phytochemicals are considered as the basis for their medicinal activity.

Keywords: Altitude, medicinal plants, phytochemicals, stress.

Introduction

Plants are the largest biochemical and pharmaceutical stores ever known on our planet. These are essential natural resources which constitute one of the potential sources of new products and bioactive compounds which could serve as newer leads and clues for modern drug design [1]. In the past two decades, nearly two thirds of approved new drugs were obtained from natural plant products [2]. Majority of the world's human population relies on medicinal plants for its primary pharmaceutical care [3]. Today there is a wide spread interest in drugs derived from plants as these plant based products are used to treat even deadly diseases like AIDS and cancer. The so called "Wonder Drugs" of the recent past that revolutionized modern medicinal practices have almost all been first isolated from plants employed for one purpose or another in our primitive or ancient culture. Reserpine, colchine, podophyllotoxin, vinblastine, strophanthine, steroids and cortisones are some examples [4].

Table 1: Influence of some environmental factors on secondary metabolite production in some medicinal plant species (Source: Ncube *et al*. [20])

Environmental stress factor	Plant Species	Secondary metabolites
Temperature	*Hypericum perforatum* *Achnatherum inebrians* *Arnica montana* *Quercus* spp. *Pachypodium saundersii,* *Petunia×hybrida*	Terpenoids, anthocyanins, Phenolic compounds alkaloids, flavonoids, tannins;
UV Light/ Solar radiation	*Betula* spp., *Salix myrsinifolia, Secale cereal, Artemisia annua, Sambucus nigra, Prunus serotina, Frangula alnus, Corylus avellana, Pteridium arachnoideum, Solanum tuberosum, Diplacus spp., Larrea, Marchantia polymorpha, Pinus taeda, Arabidopsis thaliana, Cornus sanguinea,*	Terpenoids, flavonoids, hydroxycinnamic acids, tannins, artemisinin, phytosterols, glycoalkaloids, luteolin, apigenin, alkaloids, flavonol glycosides, phenolic acids;
Soil nutrients	*Ceratonia siliqua, Lithopermum erythrorhizon, Betula spp., Eucalyptus cladocalyx, Rhodiola sachalinensis , Aradopsis thaliana,*	Phenolic compounds, gallotannins, shikonin, cyanogenic, glycosides, Salidroside, condensed tannins
Moisture	*Artemisia annua, Pachypodium saundersii, Achnatherum Inebrians, Pteridium arachnoideum,*	Lipophilic resins, artemisinin, tannins, isoprene, anthocyanins, alkaloids, Phenolic compounds

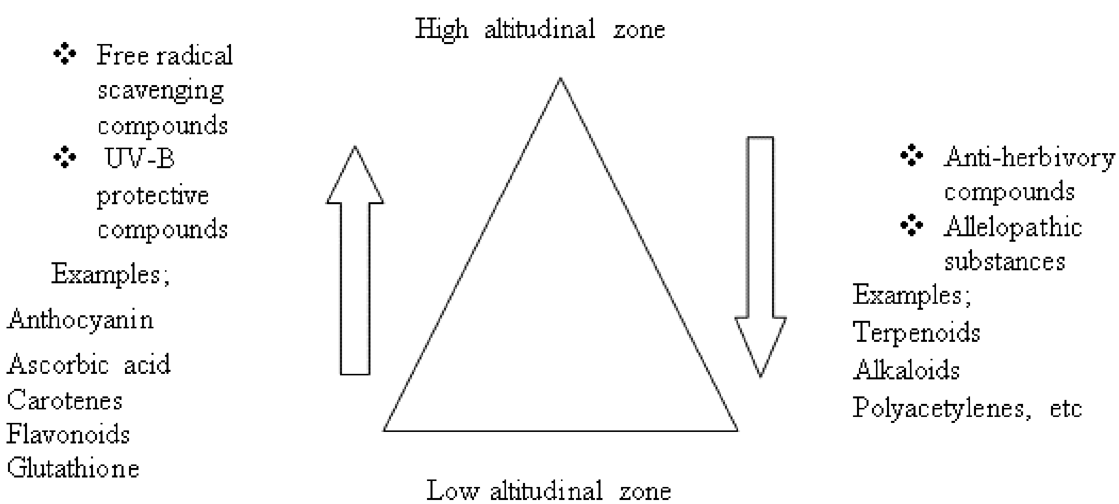

Fig. 1: Altitudinal trends predicted for various classes of plant secondary metabolites with differing ecological functions (Source: Zidorn [46])

The medicinal value of plants emanate from some bio-active substances known as phytochemicals or secondary metabolites. Plants have an almost limitless ability to synthesise these metabolites. There are diverse array of phytochemicals but the most important of these bioactive constituents of plants are alkaloids, tannins, flavonoids and phenolic compounds. These phytochemicals accumulate in different parts of the plants, such as in the roots, stems, leaves, flowers, fruits or seeds [5].Knowledge of the chemical constituents of plants is desirable, not only for the discovery of therapeutic agents, but also because such information would help in disclosing new sources that can act as precursors for the synthesis of complex chemical substances. It can further be valuable in discovering the actual value of folklore remedies [6]. It is well-known that plants produce these chemicals to protect themselves. The large diversity of chemical types and interactions displayed by the secondary metabolites can underlie the impressive multiplicity of protective functions ranging from toxicity and light/UV shielding to signal transduction [7]. But recent researches demonstrate that many phytochemicals can also protect humans against diseases [8]. Thus, there is a need to encourage the use of medicinal plants as potential sources of new drugs.

ALTITUDINAL VARIATION OF SECONDARY METABOLITES IN PLANTS

Biosynthesis of secondary metabolites is not only controlled genetically, but is also strongly affected by different biotic and abiotic stresses.Abiotic factors often have an especially large influence on the biosynthetic levels andquality of secondary metabolites in plants [9]. A broad array of environmental factors change with altitude. These factors include precipitation, mean temperature, daily thermal amplitudes, soil characteristics, wind speed, temperature amplitudes, soil characteristics, temperature extremes, atmospheric pressure, duration of snow-cover, length of the vegetation period, and radiation intensities [10]. A change in these factors with the change in the altitude exposes the plants to a variety of stresses both biotic and abiotic. Since plants are immobile, so in order to survive and reproduce within their natural ecological niches these must cope up with a variety of stresses by means of various physiological and biochemical mechanisms including evolution of a resistance-conferring genotype, or by improvement of genes which can produce ecologically adapted phenotypes or can have a different response related to their resistance to these stress conditions which depends mainly on the morphology, anatomy and life cycle. In response to different environmental conditions, plant's defence mechanisms respond differently (Table 1). Thus the stress conditions affect the synthesis of secondary metabolites and other compounds that plants produce, which are usually the basis for their medicinal activity [11].

Several explanations have been advanced for altitudinal variations in the phytochemical constituents of plants:

1.According to one view the amounts (and diversity) of bioactive natural products decreases from low to high altitude [12] because of less pronounced selective pressure by herbivores whose numbers and diversity decrease from low to high altitudes leading to decrease in antiherbivory compounds from low to high altitudes. They have reported that high altitude populations of *Lupinus argenteus* contain significantly lower amounts of toxic alkaloids in their leaves as compared to low altitude populations. Maithani *et al*. [13] reported highest berberine content (2.94%) in *Berberis asiatica* from lower altitudes as compared to higher altitudes (2.20%). Salmore and Hunter [14] opined that in general, alkaloid content in bloodroot rhizomes decline with elevation.

2.Another view holds that climate extremes with regards to radiation and temperature are stress factors to plants and the bioactive compounds alleviating the impact of e.g. low temperatures or enhanced UV-B radiation increase in high latitudes and high altitudes.This theory was supported by the work conducted on flowering heads of *Matricaria chamomilla* cv. BONA in which both flavonoid and phenolic acid showed positive and statistically significant correlations with the altitude of the growing sites[15]. Kishore*etal*. [16] conducted studies on the seeds and hull of Tartar buckwheat and showed that the total polyphenol and antioxidant potential increase with rising altitude. The contents of epigallocatechin gallate, catechinn gallate and catechins in Oolong tea grown at high altitudes were significantly high than those grown at low altitude [17].

Monschein *et al*. [18] reported that phenolic compounds particularly flavonols showed significant differences in samples collected at different altitudes with increased levels of quercetin glycosides at higher altitudes. Gnanasekaran*et al*.[19] reported that the flower and the leaf extracts of *Tridax procumbens* L.from hilly-terrain expressed the highest total phenol and flavonoid contents, compared to the respective extracts of the dry and the wet-lands. Amongst all the extracts made, the flower extract of the hilly-terrain showed the lowest IC50 value and the highest *in vitro* free radical scavenging activity because of the highest contents of the flavonoids and total phenols. The overall amount of phenolic acids and neolignan of entire leaves increased with altitude while the total amount of flavonoids in leaf cuticles decreased in *Buxus sempervirens*[20]. An increase in alkaloid and tannin content was observed in *Primula denticulate* with the rise in altitude.The alkaloid content (sanguinarine and berberine) of root extracts of *Chelidonium majus* exhibited a direct with the altitude. As per Yong-Xing *et al*. [21] the total alkaloid showed significant negative correlation with the altitude in flue-cured tobacco, wherein thepercentage of nicotine increased with the increase in altitude and the percentages of nornicotine, anatabine and total micro alkaloid negatively correlated with altitude. They concluded that the flue-cured tobacco grown at higher altitude would have better smoking quality, because of higher percentage of nicotine and lower percentages of nornicotine, anatabine and total microalkaloids in total alkaloid, and the irritation of tobacco smoke would be reduced.Altitudinal trends for various classes of secondary metabolites according to the two presented theories and according to existing experimental data are summarized in Figure 1. A concomitant increasein secondary metabolites (alkaloids, flavonoids and essential oil content was recorded from 760 to 2580 m height by Khan *et al*. [22]. Altitudinal variation of some phytochemicals are summarized in Table 2:

Table 2: Effect of elevation on different secondary metabolites in plants

Plant species	Secondary metabolites	Impact of elevation
Lupinus argenteus	Alkaloids	Suppressed
Betula pendula	Flavonoids	enhanced
Artemisia vulgaris	Apigenin	Enhanced
Hypericum	Hypericin	enhanced
***Matricaria chamomilla* cv. BONA**	Flavonoids and Phenolic acid	Enhanced
Juniperus communis	TerpenoidS	enhanced
***Camellia sinensis* (Oolong tea)**	Epigallocatechin gallate, Catechinn gallate and Catechins	enhanced
Crocus sativus	crocin, picrocrocin, and safranal	enhanced
Eucommia ulmoides	Chlorogenic acid and Flavonoids	enhanced
Pistacia lentiscus	Terpenoid	enhanced
Tartary buckwheat	Rutin and Phenolic acids	enhanced
Black teas	Theaflavins	enhanced
Coffea Canephora	Nicotinic acid and Trigonelline	enhanced
Desmodium gangeticum	Lupeol	enhanced
Berberis asiatica	Berberine	Suppressed
Primula denticulate	Alkaloids and Tannins	enhanced
Artemisia judiaca	Artemisin, Alkaloids, Flavonoids	enhanced
Potentilla fruticosa	Flavonoids, Rutin, Phenolics	enhanced
	Tannins	supressed
Ajuga bracteosa and Ajuga parviflora	Phenols, Terpenoids, Alkaloids, Flavonoids, Saponins	enhanced

CONCLUSION

The Plants have the ability to synthesize a wide variety of chemical compounds that are used to perform important biological functions, and to defend against attack from predators such as insects, fungi and herbivorous mammals. Throughout the world medicinal plants have formed the basis of health care since the earliest days of humanity and are still widely used and have considerable importance in international trade. The quality and quantity of secondary metabolites in medicinal plants is strongly dependent on the growing conditions and synthesis is regulated by external environmental stresses. Since plants cannot escape from the environmental extremes of light, temperature, and drought, nor move to regions with better nutritional conditions, they have thus evolved highly complex mechanisms to integrate physiology and metabolism in order to adapt to the conditions to which they are exposed. Secondary metabolites form an integral component of these adaptive mechanisms. Plants have acquired a range of mechanisms to sense their environment and modify their growth and development as required. Hence, understanding how environmental factors affect the production of secondary metabolites is of great importance for the conservation of medicinal plants and optimizing field growth conditions for maximal recovery of phytomedicinal chemicals.

Therefore, there is need to explore huge number of species to find out whether the observed trends are taking place in the majority of plants or are restricted to the investigated model species. In conclusion, study of effect of altitudinal variation in plant secondary metabolites contents offers a wide range for future studies, applicable for both ecology and medicinal plant research.

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