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Impact of drought stress signals on growth and secondary metabolites (SMs) in medicinal plants

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ABSTRACT

Medicinal plants having diversified phytochemical compounds like secondary plant metabolites (alkaloids, terpenoids, phenols, steroids, flavanoids, tannins, cyanogenic glycosides and glucosinolates, essential oils and aromatic compounds etc) are subject to abiotic stress like drought. Drought, one of the major ecologically limiting factors has significant impact on growth and secondary metabolic process of several medicinal plants. Water stress causes a reduction in plant size, density, reduces plant leaf area, and decrease in whole biomass, and not only alters the plant structurally and anatomically but also leads to fluctuation of their secondary chemical constituents. Secondary plant metabolites (SPMs) are useful to assess the quality and quantity of the therapeutic ingredients and such metabolites synthesized by the plant helps to cope up towards the negative effects of stress for adaptation and defence. A large number of studies manifested from the relevant review that drought influences on SPMs production and accumulation from plant parts like roots, stems, leaves, flower, fruits, seeds etc and causes an increase or decrease in their solute concentration by up to 50%.

Studies showed that a medicinal plant produces different concentration of a particular metabolite grown under stress and non-stress environment. Generally, drought stress accumulates a higher concentration of active phytochemicals like alkaloids, tannins, terpenoids etc whereas concentration of phenols, flavanoids and saponins etc decreases under drought. In most cases as a whole, it may have to be concluding from comparative analysis that medicinal plants grown under drought exhibits higher content of secondary plant products than grown under optimal conditions. In addition, all secondary products may not increase in equal proportions under stress and it depends on the intensity of the drought as well as species of medicinal plants. Thus, moderate drought stress significantly enhanced the quality as well as quantity of secondary active substances in medicinal plants. However, for better understanding in-depth further research is utmost essential at molecular level using new techniques viz. Proteomics, metabolomics, transcriptomes and genomics etc.

Keywords: Drought stress, Growth, Metabolism, Secondary plant metabolites (SPMs), Medicinal plants.

INTRODUCTION

Medicinal plants, a rich source of diverse active phytochemicals are now subject to drought stress during their growth and development. Drought stress is the most dominant abiotic stress that adversely affect majority of the crops. It creates an imbalance between ROS (Reactive Oxygen Species) generation and antioxidant defence system in plants that results in the accumulation of ROS causes oxidative damage of several biomolecules like lipid, protein etc. In medicinal plants, drought stress reduces the growth of the plant due to several reasons viz. Reduced canopy absorption of PAR (Photosynthetically Active Radiation, 400-700nm), reduced photosynthesis by disturbing stomatal functioning and damaging photosynthetic apparatus by ROS generation, early leaf senescence, reduced leaf area expansion, reduce the radiation use efficiency, reduced net CO_2 exchange rate per unit of absorbed PAR, reduced biomass accumulation, decreased vegetative dry matter and reduced harvest index etc.

Based on the plant physiological and biochemical considerations, drought stress induces the oversupply of strong reducing equivalents like $NADPH_2$ that is reoxidized by photorespiration or violaxanthine cycle in order to prevent oxidative damage.

On the other hand, drought stress strongly influences on synthesis and accumulation of secondary plant products and may causes an increase in active solute concentration in medicinal plants, however only very limited information regarding these are available based on physiological consideration. Drought has strong impact on general plant metabolism and influence metabolic pathways responsible for synthesis and accumulation of secondary plant products in medicinal plants. On an average, medicinal plants grown under semi-arid conditions produce higher concentration of active phytochemicals than same species grown under moderate climatic conditions as observed and manifested from a large number of studies.

Impact of drought stress on growth of some medicinal plants

Drought stress reduces plant height, decrease the number and area of leaves, reduces fresh and dry weights of the leaves, significant reduction in root length and weight, reduced the content of leaf photosynthetic pigments etc. Due to reduced vegetative growth period, plants move to flowering stage and ultimately yield of the medicinal plants reduced under drought. However, detrimental effects on all the growth and developmental process of medicinal plants greatly rely upon the intensity, rate and duration of the exposure to stress [1].

Drought stress reduced the plant height and causes smaller leaf area in *Mentha arvensis* [2]; *Calendula officinalis* [3] and *Cichorium intybus* [4] in the early vegetative growth period and drought may limit the grain yield of several medicinal plants by reducing the harvest index. In some lemon grass species viz. *Cymbopogon nardus* and *Cymbopogon pendulu*; water deficit causes a significant reduction in plant height, leaf area, fresh and dry weight of the leaves, moisture content and essential oil content [5]. Such stress during reproductive stage which is very sensitive period leads to shortage the interval of seed formation to pollen shed and thereby shortens the grain filling period. On the contrary, mild drought stress at 50% soil moisture level causes an increase in plant height, leaf area, number of branches and leaves, fresh and dry biomass of *Ocimum basilicum* L. while further increase in stress level causes a reduction in these growth parameters [6].

Thus, suggestions from the several comprehensive report and reviews it may be concluded that extreme water stress severely affect the growth and development of medicinal plants but under mild water stress at certain level may cause growth enhancement of medicinal plants, in general. Some stress induced growth inhibition are represented and reviewed in Table 1.

Table 1: Effect of drought stress on various growth characteristics of medicinal plants.

Plant species	Common name & Family	Changes in growth parameters under drought stress	References
Catharanthus roseus L. (Formerly known as *Vinca rosea* L.)	Bright eyes, Madagaskar periwinkle, Rose periwinkle, Nayan tara Apocynaceae	Reduced biomass production, leaf area, root-shoot length, fresh and dry weight of plants and content of photosynthetic pigments, decrease in net assimilation rate and harvest index.	[7]
Withania somnifera (L.) Dunal	Ashwagandha, Winter cherry, Indian ginseng, Horse smelling Solanaceae	Reduced leaf area, net photosynthesis rate and chlorophyll content under severe water stress. Decreased in leaf water content, stomatal conductance, net photosynthetic rate, transpiration rate, and reduced chlorophyll content, quantum yield of PSI and PSII decreased. Significant reduction in root and shoot length, leaf area, fresh mass and dry mass and decrease in photosynthetic pigment as well as photosynthetic activities.	[8] [9] [10]
Stellaria dichotoma L. var. lanceolata Bge	Chickweed, American chickweed Caryophyllaceae	Root biomass formation increases first then decreases with the increasing stress level. RWC in leaves noticeably decreases but leaf tissue density increases with the increasing of water stress level. Moderate stress with 60-70% or 80-90FC% FC was optimum for roots biomass formation.	[11]
Trachyspermum ammi L.	Ajwain, Ajowan, Omni podi, Thymol seeds, Bishop's weed or carom Apiaceae	Plant height, fresh and dry weight, transpiration rate and stomatal conductance reduced with the increasing the intensity of drought stress.	[12]
Ocimum basilicum L.	Basil, holy basil, tulsi Lamiaceae	Plant height, amount of dry weight, dry weight per plant, sub-shrub and internodes number reduced with the increasing the level of stress.	[13]
Ocimum basilicum L.	Basil, holy basil, tulsi Lamiaceae	Plant height, stem diameter, number and area of leaves, LAI, herb yield etc are significantly reduced.	[14]

Impact of drought stress on secondary plant metabolites (SPMs) of various medicinal plants

As evidence from reviews, drought stress directly influences the metabolic pathways responsible for the synthesis as well as concentration of secondary metabolites accumulated in medicinal plants whereas stress accumulate comparatively higher concentrations of metabolites like phenols, terpenes, essential oils and N-containing metabolites (alkaloids, cyanogenic glucosides, glucosinolates and non-protein amino acids) etc than well-watered plants. There is evidence suggest that synthesis and concentration of secondary metabolites significantly differ under various degree as well as intensity of drought. In some cases, it was reported that severe stress causes a significant reduction in both the synthesis and concentration of the secondary metabolites and thus moderate water stress is optimum for active ingredient accumulation as well as suitable for increase their concentration as an appropriate degree of drought stress may promote the synthesis and accumulation of active metabolites by stimulating the expression of corresponding genes and activates the key enzymes involved in the biosynthesis and accumulation of metabolic compounds.

Drought stress reduces the total phenols and flavonoids content whereas tannins, terpenoids and alkaloids increases in *Mentha piperita* L. and *Catharanthus roseus* L. [15]. It was also demonstrated that there was a significant increase in the accumulation of alkaloids by expressing the gene regulating secondary metabolites accumulation in *Catharanthus roseus* L. leaves [16]. Other results demonstrated by [17] that *Scutellaria baicalensis* Georgi, commonly known as Baikal Skullcap or Chinese Skullcap that is used as an herb in traditional Chinese medicine to treat various diseases and under mild drought stress it's flavonoid (Baicalein) content increases but decreases under severe stress conditions. As a whole, it may undoubtedly be concluded that drought stress consistently induces the biosynthesis and accumulation of secondary plant products where we consider the stress induced reduction of plant growth.

Therefore, by considering the reduction in overall biomass of the metabolites even though their concentration on dry or fresh weight basis may be increased under drought stress. However, further research on medicinal plants needs to be more important on this aspects. Corresponding increase or decrease are reported for simple as well as for complex phenols, various classes of terpenes; alkaloids, glucosides, glucosinolates and non-protein amino acids and other essential oils are reviewed and represented in Table 2, 3 & 4 respectively.

Table 2: Changes in the concentration of various secondary plant products like simple and complex phenols and terpenes etc under drought stress.

Plant species	Common name & Family	Secondary plant products	Plant parts	Changes in the concentration of SMs	References
Hypericum brasiliense L.	Choisy, St. John's Wort Guttiferae	Betulinic acid Total phenols Rutine Dihydroxy-xanthone	-	About 60% increase in concentration of Betulinic acid. Over 80% increase in total phenol concentrations. About 5-times increase in rutine. Over 300% increase in dihydroxy-xanthone.	[18]
Ocimum tenuiflorum L.	Holy basil, tulsi, tulsai Lamiaceae	Eugenol (Phenol)	Leaf	Decrease	[19]
Stellaria dichotoma L.	Chickweed, American chickweed Caryophyllaceae	Total saponins and flavonoids	Leaves, roots	Increase	[20]
Pisum sativum L.	Garden pea Fabaceae	Flavonoids Anthocyanins	-	Flavanoids concentration increases about 45 %. Anthocyanin concentration increases over 80 %.	[21]
Camellia sinensis L.	Tea Theaceae	Catechins and Epicatechins (Polyphenolics)	-	Massive increase in catechin and epicatechin concentrations.	[22]
Helianthus annuus L.	Sunflower Asteraceae	Chlorogenic acid	-	10-times more increase in concentration of Chlorogenic acid.	[23]
Thymus capitatus L.	Headed Savory, Thymus Lamiaceae	Phenolics	-	Concentration increases under stress	[24]
Prunus persica L.	Peach Rosaceae	Total phenols	-	Concentration increases under stress	[25]
Echinacea purpurea L.	Purple coneflower Asteraceae	Total phenols	-	67% increase in total phenols	[26]
Trachyspermum ammi L.	Ajwain, Ajowan, Omni podi, Thymol seeds, Bishop's weed or carom	Total phenols	-	Strong increase (100 %)	[27]
Salvia officinalis L.	Culinary sage, garden sage. Lamiaceae	Polyphenols	-	Significant increase	[28]
Melissa officinalis L.	Lemon balm, balm mint Lamiaceae	Polyphenols	-	Significant increase	[28]
Vitis vinifera L.	Grapevine, winegrape Vitaceae	Flavanoids	Leaves	Significant increase	[29]
Ocimum basilicum L.	Basil, holy basil, tulsi Lamiaceae	Anthocyanin	Leaves	Significant increase	[30]
Cyperus rotandus L.	Purple nutsedge, nutgrass Cyperaceae	Phenolics and terpenoids	-	Significant increase	[31]

Table 3: Changes in the concentration of various nitrogen containing plant metabolites like alkaloids, glucosides, glucosinolates and non-protein amino acids under drought stress.

Plant species	Common name & Family	Secondary plant products	Plant parts	Drought effect	References
Papaver somniferum L.	Opium poppy Papaveraceae	Morphine, codeine, and papaverine alkaloids	Unripe seed capsule and plantlets	Increase in alkaloids concentration	[32]
Withania somnifera (L.) Dunal	Ashwagandha, Winter cherry, Indian ginseng, Horse smelling Solanaceae	Withanolides (a group of C28-steroidal lactone triterpenoids)	-	Withanolides were also increased with enhanced detoxification and osmotic regulation under drought stress.	[33]
Withania somnifera (L.) Dunal	Ashwagandha, Winter cherry, Indian ginseng, Horse smelling Solanaceae	Withanolide and 12-deoxywithastramonolide	-	Withanolide and 12-deoxywithastramonolide are reduced up to 65% and 78%.	[34]
Withania somnifera (L.) Dunal	Ashwagandha, Winter cherry, Indian ginseng, Horse smelling Solanaceae	Withaferin A (triterpenoid)	Leaves, roots	Concentration of Withaferin A was increased 5 % under stress.	[35]
Centella asiatica L.	Gotu kola, Than Kuni, Kodavan, Indian pennywort and Asiatic pennywort Mackinlayaceae/Apiaceae	Asiaticoside and madecassoside	Leaves (post-harvest)	Increase under low temperature and drought	[36]
Brassica napus L.	Canola/ rape/ rapeseed Brassicaceae/ Cruciferae	Glucosinolates (mustard family glucosides)	Seeds	Massive ncrease in glucosinolates concentration	[37], [38]

Brassica oleracea L.	Cabbage Brassicaceae	Glucosinolates	Leaves	Significant increase	[39]
Brassica carinata L.	Abyssinian cabbage, Abyssinian mustard, Ethiopian mustard, Ethiopian rape Brassicaceae	Glucosinolates	Leaves	Significant increase	[40]
Glycine max L.	Soyabean Fabaceae	Trigonelline (alkaloids)	Dried seeds	Increase in Trigonelline concentration	[41]
Manihot esculenta L.	Cassava/Tapioca/manioc / mandioca Euphorbiaceae (Castor family)	Cyanogenic glucosides	Tubrous roots and leaves	Strong increase in glucosides concentration	[42], [43]
Lupinus angustifolius L.	European blue lupine, Australian lupin, Narrow-leaf lupin Fabaceae	Quinolizidin alkaloids	Seeds	Strong increase	[44]
Eucalyptus cladocalyx L.	Sugar gum/Gum tree Myrtaceae	Cyanogenic glucosides	Dried leaves and oil	Increase in glucosides concentration	[45]
Catharanthus roseus L. (Formerly known as *Vinca rosea* L.**)**	Bright eyes, Madagaskar periwinkle, Rose periwinkle, Nayan tara Apocynaceae	Indole alkaloids	-	Strong increase	[46]

Table 4: Drought stress-induced changes in the concentration of various essential oils found in medicinal plants.

Plant species	**Common name & Family**	**Secondary plant products**	**Plant parts**	**Drought effect**	**References**
Mentha x *piperita*	Peeper mint, mentha Lamiaceae	Menthol	Leaves	Significant increase	[47], [48]
Cymbopogon pendulus L.	Lemongrass, barbed wire grass, Cochin grass, Malabar grass Poaceae	Geraniol and citral	Leaves	Strong increase	[49]
Salvia officinalis L.	Culinary sage, garden sage. Lamiaceae	Essential oils	Leaves	2 to 4 times substantial increase of essential oils	[50]
Petroselinum crispum L.	Parsley, garden parsley Apiaceae	Essential oils	-	Increase in large extent (double)	[51]
Ocimum basilicum L.	Basil, holy basil, tulsi Lamiaceae	Essential oils	-	Noticeable increase	[52]
Thymus vulgaris L.	Thyme, garden thyme	Thymol	Leaves	Significant increase	[53]

CONCLUSION AND FUTURE PROSPECTUS

Medicinal plants are rich sources of chemically diverse group of bioactive components that are used in nutraceutical, cosmetic, chemicals and pharmaceutical industries and traditionally used for treatment of several diseases etc. These phytochemical constituents popularly known as Secondary Plant Metabolites (SMPs) and abiotic stress such as drought significantly alter the overall biosynthesis, allocation and accumulation of SMs specifically in medicinal plants by modulating physiological and biochemical mechanisms of certain organs or tissues. Therefore, drought stress always considered as negative factors responsible for reducing growth and yield losses but there is something different in respect to medicinal plants as compared to other plants where stress frequently leads to enrichment of the synthesis, contents or concentration of bioactive secondary metabolites as well as increasing the quality of the natural products and such enhancement might have to be compensated or even overcompensated with other metabolic responses like growth reduction, biomass reduction etc. As out lined above, a considerable number of bioactive compounds and their concentration may be induced by moderate drought stress associated with a significant reduction of biomass production, thus a putative gain in quality of SMs would be compensated by growth and yield loss as quality of active compounds is much more relevant than total yield.

Thus, quality improvement might have to be seems very promising as demand for herbal medicinal plants and their bioactive components are increasing day by day. For this, a solid and comprehensive research of the conjuncture is required that explore the details of morphological, physiological, biochemical and molecular mechanisms of medicinal plants grown under water stress, though for proper identification of useful medicinal plants and extraction as well as evaluation of their bioactive compounds and their understanding of biosynthetic pathways needs to be done by taking certain challenges using several recently developed transgenics and other novel approaches.

Conflict of Interest

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