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Impact of climate change on physiology of medicinal and aromatic plants

Medicinal plants are valuable resources for drug development and therapeutic nutrition, supporting health care and livelihood of tribal and rural communities. Global warming, caused by increased greenhouse gas emissions leads to change in climate resulting in altered seasonal patterns, weather events, and temperature ranges worldwide, which is a significant concern for agriculture. Agriculture contributes to greenhouse gas emissions, with nitrogenous fertilizers and deforestation being major sources of N_2O emissions. Greenhouse gases like CH_4 and N_2O have a much higher radiative impact than CO_2, exacerbating global warming. Changing climate conditions impose various abiotic stresses on medicinal plants, affecting their growth and secondary metabolism. The response of medicinal plants to stress varies depending on the species, growth stage and environmental conditions, making it challenging to define an optimum stress condition for quality produce. This article describes the impact of climate change on physiology of medicinal and aromatic plants.

THE medicinal plants are being exploited for being rich resources of ingredients used in drug development and synthesis. Apart from that, several plants are recommended for their therapeutic use as important source of nutrition. They contribute to our health care and provide livelihood to tribal and rural people. Global warming is an increase in average temperature of the earth structure. The climate is the primary determinant of agricultural productivity and therefore, in a developing country like India, change in the components of the climate responsible for the global warming is an issue of great concern. The impact of climate change is noticed in the form of changed seasonal patterns, weather events, temperature range and other related phenomena worldwide. Increase in carbon dioxide gas; a significant greenhouse gas, along with other greenhouse gases during last 100 years as a result of burning coal and oil at homes, factories, and transportation is witnessed. The global warming periods can be divided in to two main periods of warming, between 1910 and 1945 and from 1976 onwards. The Inter-governmental Panel on Climate Change (IPCC) observed that anthropogenic activities such as fossil fuel burning and deforestation led to increased concentrations of greenhouse gases since the middle of the 20th century causing increase in average temperature. Comparing to the past, this addition of greenhouses gases caused the earth to warm more quickly and there is clear evidence that the earth's climate is warming at an unprecedented rate.

Mild stress conditions may stimulate secondary metabolite production without significant harm to biomass yield in some medicinal plants but, a severe and a prolonged stress condition always imposes negative impact on the primary as well as the secondary metabolism resulting in a compromised biological yield with poor quality. Climate change can also impact pests and diseases in medicinal plants, affecting the well-being of communities relying on them for cultivation and medicine production. Future research should focus on physiological responses to specific and a defined level of stress, at a particular stage of the growth and drawing a correlation with productivity and quality of a particular medicinal plant.

Role of agriculture in climate change

Agriculture contributes to greenhouse gas emissions however; the quantum of emission varies with individual greenhouse gas and the location. In general, practicing agriculture, using nitrogenous fertilizers such as anhydrous ammonia and deforestation, causes highest contribution of total N_2O emissions. The loss in the form of N_2O is nearly 7% of total nitrogen applied as anhydrous ammonia in agricultural use. Emission of CH_4, another prominent greenhouse gas, is reported primarily from rice production and rearing livestock. The bifurcation of the emission showed that agriculture contributes 60% CH_4, with 30% of total CH_4 from rice production and 15% from livestock. Though, the CH_4 and N_2O are much smaller constituents of the earth's atmosphere than is CO_2, the increasing rice area and livestock numbers worldwide makes the emission of CH_4 and N_2O alarming. For example, the present atmospheric concentration of CO_2 is 350μmol/mol whereas the concentration CH_4 and N_2O is currently 1.7μmol/mol and 0.3μmol/mol, respectively in the atmosphere. However, the fact is that the molecule of

CH_4 and N_2O is more radiatively active than a molecule of CO_2 (N_2O is >200 times as active as CO_2 as a greenhouse gas). The increase in mean temperature over a time of period is observed due to the increase in total greenhouse gases. Thus, the climate change can readily alter rainfall pattern and necessitate large-scale population movement and primary changes in agriculture.

Secondary metabolism in plants under changing climatic scenario

Increase in the concentration of greenhouse gases imparts the stressful condition to all living beings through changing global temperature regimes, rainfall pattern, extreme events and other associated effects. Persistent changes in the environmental conditions makes plants susceptible to majority of abiotic stresses like drought, deficiency of nutrient, high and low intensity of light, ozone as well as UV-B radiation, salinity, low and high temperature and heavy metal toxicity. Like all living members of the biosphere, medicinal plants also get affected by climate change. Climate change is causing noticeable effect on the life cycles and distribution of the medicinal plants besides affecting primary and the secondary metabolism in such plants. In general, abiotic stresses restrict growth and thus cause loss of production in terms of biological yield in plant. The energy in the form of light incident on leaf driving photosynthesis in green plants have three fates. The incident light absorbed have competition among i) photochemistry, ii) heat dissipation through non-photochemical quenching, and iii) chlorophyll fluorescence reflecting back the light. The transport of electrons and protons from water to nicotinamide-adeninedinucleotide-phosphate (NADP) and also in the phosphorylation of ADP to ATP is the main route through which the absorbed light energy is utilized. The energy in the form of electron may be used in defense mechanism by antioxidant enzymes activation to prevent stress impacts at cellular level. During initial and mild stress conditions, the plant balances the osmotic conditions in cells and manages a suitable stomatal movements intended to fulfil CO_2 requirement through stomatal pores. During this stage, the PS II and membrane integrity are not permanently damaged and hence, the decline in growth is not significantly affected. In medicinal plants, it is basically a kind of trade-off between two traits worth to understand: i) weakening primary metabolism as a sink leading to retarded growth, and ii) strengthening secondary metabolism as a sink leading to increased yield of secondary metabolites.

A prolonged severe stress conditions has different consequences on physiology of medicinal plants. A significant decrease in biomass and yield of seeds in plants due to elevation of stress caused by drought and other associated stresses is reported. Benefits of elevated secondary metabolites may be achieved in medicinal plants at the cost of sacrificing the biomass yield under stress condition. Evaluation of photosynthetic activities and physiological state based on the time dependent changes of the chlorophyll A fluorescence has become the routine investigation in plant studies especially under stress environments. The application of chlorophyll A fluorescence imaging in plant research is growing rapidly, ranging from basic research at the cell and sub-cellular level to biotechnology or remote sensing of plant canopy and this technique has been developed as a versatile tool for determining and understanding the heterogeneity in a leaf photochemical efficiency. The data on chlorophyll fluorescence parameters explaining damage via photo-inhibitory action had been used to differentiate between susceptible and tolerant genotypes of plants. A severe and prolonged stress condition disrupts membrane integrity and causes permanent damage to PSII leading to a decline in maximum (Fv/Fm) and thereby actual photosynthetic efficiency (F'v/F'm) in plants. It is accompanied with drastic decline in stomatal conductance in accordance to prevent water loss besides making a huge stomatal limitation to CO_2 influx which is one of the reasons to reduced F'v/F'm.

Hypothetically, in medicinal plants, a stress condition called optimum stress condition is one in which there is increase in secondary metabolites without significantly affecting the biological yield. However, a wide spectrum of group of secondary metabolites, different pheno-phases, preferred plant part for accumulation of secondary metabolites and life span makes it difficult to define an optimum stress condition. Further, soil type and climatic conditions of a region, continuous or simulated stress, duration of stress and coinciding phenophase makes the conditions very difficult in defining the optimum stress condition. A comprehensive response of different stress conditions at different growth stages on secondary metabolites content and growth in various plants is reviewed.

Recently, genotypic variation in andrographolide content is reported and their interaction with water deficit stress condition at different growth phase showed mixed response to andrographolide content in *A. panicuata* genotypes. In spite of increased per cent active ingredient content in some genotypes, a drastic decline in biological yield resulted in lower andrographolide yield in *A. panicuata.* It is believed that a medicinal plant grown in semi-arid regions has elevated concentrations of active substances, i.e., secondary metabolites. Even stimulation of drought stress during the cultivation of medicinal plants is reported to impact product quality. Stomata have a great role to play in this case. Under normal conditions, the primary metabolism is the sink of electron flow. However, under stress conditions, the sink is shifted towards the secondary metabolism. Explanation for stress-induced enhancement of natural products at anatomical level of stomata can be attributed to stress condition causing closing of stomata which reduces markedly the uptake of CO_2. Integration of environmental signals and endogenous hormonal stimuli regulates the opening and closing of stomata in plants. A complex network of signalling pathways controlling stomatal movements are activated in guard cells. Abscisic acid (ABA), a hormone of sesquiterpene origin is a stress hormone causing closure of the stomata. Other phytohormones, like brassinosteroids and cytokinins also playing a role in stomatal development are involved in opening and closing mechanism in stomata. Jasmonic acid and ethylene are also involved in the stomatal response to stresses. ABA interacts with jasmonic acid and nitric oxide and this interaction results in stimulation of stomatal

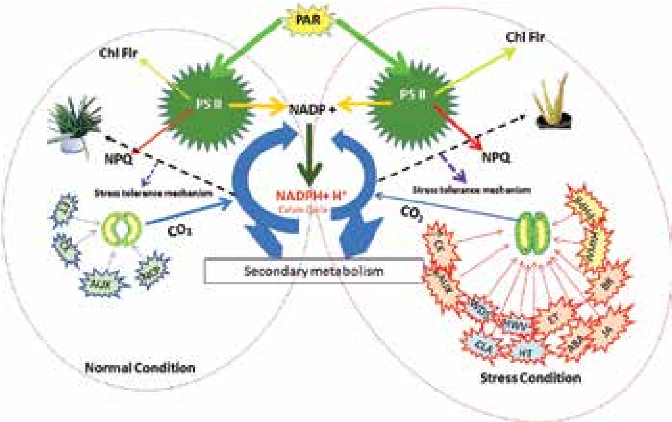

Fig. 1. Comparison of fate of absorbed light in plants under optimum and stress condition. PAR is photosynthetically active radiation, Chl Flr is chlorophyll fluorescence, NPQ is non-photochemical quenching, NADP is nicotinamide-adenine dinucleotide phosphate, ET* is ethylene, CK is cytokinins (physiological concentrations), AUX is auxin (physiological concentrations), NPC is other normal physiological conditions (absence of stress), WDS is water deficit stress, HT is high temperature, CLA is constant light absorption, HWV is high wind velocity, ABA is abscisic acid, JA is jasmonates, BR is brassinosteroids, CK implies cytokinins at high concentration, AUX implies auxin at high concentration, PHPB is exposure to plant and human pathogenic bacteria, WMIH implies wounding; mechanical; insect; herbivores. Source: Kalariya K A *et al.* (2021). Stomatal development and impact of stomatal movement on secondary metabolism in medicinal plants. *JSM Environ Sci Ecol* 9(1): 1074.

closure. As a result of partial closure of stomata due to initial or mild stress conditions, a considerable decrease in the CO_2 fixation via Calvin cycle occurs. Resultantly, the reduction equivalents ($NADPH^+H^+$) which were supposed to be utilized in primary metabolism is now made available, in a massive oversupply to secondary metabolic processes causing enhanced production of secondary metabolic processes. Some secondary metabolites as also reported to be useful in plant defence mechanism. Additionally, genes of pathways leading to secondary metabolites are also up-regulated under stress condition leading to synergistic effect in raised secondary metabolite production under adverse conditions. However, under prolonged and severe stress conditions, stomatal movement imposes a huge limitation on gaseous exchange which in turn impacts both the primary and the secondary metabolism adversely, resulting in poor quality with significant biological yield loss. This is because during mild or initial stress condition, the photosystems are not permanently damaged and secondary metabolisms are the preferred sink for phosynthates as compared to the control conditions. Under severe stress conditions, the photosystems are permanently damaged causing reduced input of photo energy under the vicinity of scarcity of intracellular CO_2 ultimately severely compromising biological yield that cannot compensate for the increase in the active ingredients (Fig. 1).

Recently in a comparative transcriptome study involving two diverse genotypes of *G. sylvestre* DGS 3 and DGS 22, five main pathways related to the photosynthesis were investigated and 123 genes were identified. The pathway leading to the biosynthesis of porphyrin and chlorophyll metabolism had 30 genes with 68% of the genes upregulated in a superior genotype DGS 22. Carotenoid biosynthesis [ko00906] was characterized by a total of 18 genes with 80% of the genes upregulated in genotype DGS 22. Even though having similar Fv/Fm, higher chlorophylls and carotenoids content, major reason behind low PN was downregulation of Rubisco small subunit (rbcS) whereas an efficient xanthophyll cycle helped better protect photosystem II (PS II) through maintaining high non-photochemical quenching (NPQ) in DGS 22. Stomata being the gateway of gaseous exchange between plant and the environment have a great role to play in deciding the photosynthesis to occur. The formation of stomata is under strict genetic control and is reviewed recently.

SUMMARY

The impact of climate change in medicinal plants may differ than that in main food crops. This is because in a field crop, the interest is to harvest more grain yield but, in a medicinal plant, the interest is to harvest more herbage yield having more active principle secondary metabolites. In most of the medicinal plants, the secondary metabolite concentration increases due to stress but, the stress related decrease in biomass generally over-compensates the increase in the concentration of relevant natural products. However, every plant contains different group of secondary metabolites, have different life span, growing season, pheno-phase, soil and climatic conditions and plant parts as specific target for secondary metabolite accumulation. Defining an optimum stress condition that favours a quality produce without deviating the potential yield is a very challenging condition. Specific responses to stress conditions in specific crops at different pheno-phases needs to be explored to understand the impact of climate change in medicinal plants. Climate change can also affect the pest and disease in medicinal plants and affect the welfare of people who depend on the cultivation of medicinal plants and the health of the people who depend on the drugs formulated from such plants. Climate change impact may have a tremendous possible effect on MAPs particularly significant due to their value within traditional systems of medicine and as economically useful plants. At this stage, the future effects of climate change are largely uncertain more so with MAPs, but current evidence suggests that these phenomena are having an impact on MAPs and that there are some potential threats worthy of concern and discussion. For future research on impact of climate change on medicinal plants depends on what kind and which level of stress will be the outcome of climate change, what is required, a high content or a bulk, vegetative or reproductive organs and exploring the source-sink transport, possibility of phytohormone application and the time of stress defining a certain phase of cultivation or a special developmental phase to obtain maximal quality.

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