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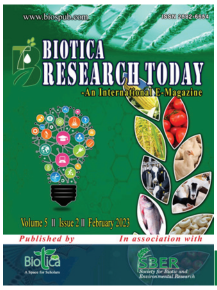

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Role of Secondary Metabolites in Drought Tolerance in Crops

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Abstract

Crops plants are subjected to a wide range of abiotic stresses in the form of heat, drought, soil salinity, acidity and water moisture stresses out of which drought stress severely affects crop productivity leading to significant yield loss. Exposure to drought stress triggers a cascade of cell signaling reactions in the plants affecting homeostasis and thereby leading to the production of an array of stress induced secondary metabolites. Intracellularly upregulated biosynthesis, osmotic regulations, metabolic shifts culminating to downstream oxidative stress scavenging are observed. Consequent morpho-physiological manifestations in form of stomatal guard cell regulations, deeper root growth, extracellular cuticle development take place. Hence the present article discusses the role of secondary phyto-chemicals and the underlying genetic factors involved in combating impact of drought stress on crops.

Keywords: Crop productivity, Drought stress, Metabolic shift, Secondary metabolites

Introduction

Plants harbor a vast range of secondary metabolites which contribute to varied functions. Unlike the primary metabolites which are synthesized for major activities related to growth and development, secondary phytochemicals contribute towards cell to cell signaling, plant defense responses, metabolic regulations and plant to plant interactions as well. The secondary metabolites mainly comprise of flavonoids, phenolics, alkaloids, secondary or tertiary acids, glucosides, osmolites and other plant hormones. These biochemicals have been characterized in many crops like reserpine in *Rauvolfia* spp. vincristine in *Catharanthus* spp., withanolides in *Withania* spp. gossypol in Cotton, oxalic acid in chickpea *etc*. Apart from their valuable importance in plant stress physiologies these secondary metabolites also have immense pharmaceutical, medicinal and ethnobotanical uses. Incidence of drought stress in plants triggers the production of ROS (reactive oxygen species) which cause an oxidative damage to the cellular systems. The ROS mainly comprise of free radicals such as hydroxyl radicals, superoxide radicals, alkoxy radicals and non-radicals such as hydrogen peroxide and singlet oxygen which inflict homeostatic disruption, damages to proteins, genetic materials and other important metabolites like lipids and carbohydrates (Yadav *et al*., 2021). Physiological activities like photosynthesis, transpiration, nitrification, carboxylation are also affected. Hence the entire network of transcriptome, proteome and metabolome of the plants are affected. To this effect plants produce certain phyto-chemicals which enable in combating the induced heat and water stress. Induced biosynthesis of such metabolites upon being triggered by appropriate transcription factors enable plants in re-stabilising the osmotic balance, maintaining the hydraulic balance and overall plant stress responses conferring drought tolerance.

Impact of Drought Stress in Different Crops

Different crops are affected variably upon drought stress affecting crop growth, development and productivity. In rice, drought stress reduces yield, affects energy metabolism during flowering and grain formation, leads to improper leaf growth, leaf senescence, poor photosynthate distribution and hence flower drop and crop failure. Similar damages are observed in maize wherein cellular damages are more. In cotton fibre quality is affected due to poor photosynthesis, membrane oxidation and phenol accumulations. In wheat, reduced grain size, seed weight, disrupted enzymatic activities, ROS formations leading to improper lipid peroxidations and nutrient assimilations are caused.

Article History

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Array of Secondary Metabolites Synthesized in Response to Drought

Plants switch to secondary metabolism upon incidence of stress. With respect to biosynthetic mechanisms and chemistry secondary metabolites are of three types: (1) terpenes comprising of carotenoids, sterols, plant volatiles and glycosides; (2) phenolics like phenolic acids, flavonoids, lignin, coumarins, lignans, tannins and stilbenes; and (3) nitrogen-containing compounds such as glucosinolates and alkaloids. Apart from the above classification other classes of phyto-chemicals are found in plants namely phytoalexins, vitamins, growth-promoting hormones. Most of the secondary metabolites are biosynthesized from primary metabolites and finally get amassed in plant cells. Their production serves as an adaptive mechanism in plants to cope with several biotic and abiotic stresses. The phenolic compounds, flavonoids and terpenoids promote in tolerance to a vast range of stresses. Their production is triggered by drought, desiccation, high light, metal toxicity, senescence, nutrient deprivation, and salinity (Davies *et al*., 2018).

Role of Secondary Metabolites

Induced secondary phyto-metabolite biosynthesis under drought stress conditions, and its cellular augmentation reduces damages caused by drought stress-induced oxidative imbalance, thereby acting as an effective defense mechanism for drought protection and improving crop sustenance and plant survival (Figure 1). Secondary metabolites moderate the cell wall and cell wall strengthening components by acting as an antioxidant layer thereby reducing membrane lipid peroxidation in plants upon stress.

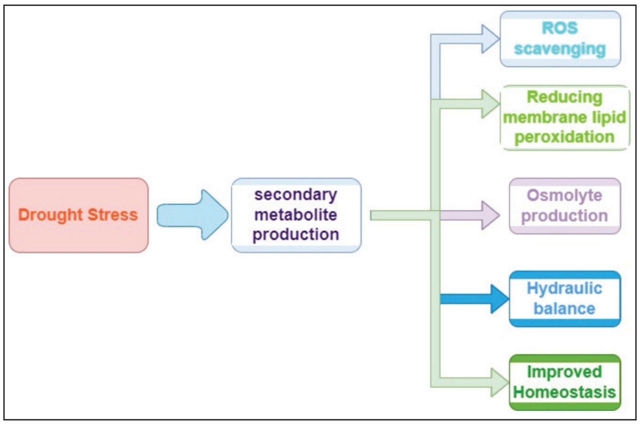

Figure 1: Role of Secondary metabolites to Drought Stress

Role of Secondary Metabolites at Metabolomics Level

Analysis of metabolic profiles has provided a holistic outline of the plant's metabolic responses to drought stress. Metabolomics is a next generation post-genomics approach to clarify the drought stress induced changes in plant metabolic system and biochemical changes by the quantitative analysis of metabolic compounds. Terpenoid secondary metabolites such as α-pinene, β-caryophyllene, camphene, limonene, modulate drought stress in plants through photosynthetic regulation, intracellular signaling and transcriptional regulations. Such activities have been observed in apple, cumin, rapeseed, grapes, cotton and potato. Phenylpropanoid metabolites with up-stimulated flavonoid, carotenoid, xanthophyll and polyphenol productions confer high temperature and moisture stress tolerance. Various research investigations elaborated that the content of phytochemicals like zealexins and kauralexins, along with terpenoids increased significantly in the roots plants. Such metabolic changes were testified through metabolomics tools such as nuclear magnetic resonance (NMR), liquid chromatography-mass spectrometry (LC-MS), and gas chromatography-mass spectrometry (GC-MS).

Genetic Engineering of Secondary Metabolite Biosynthetic Pathways

Enhancement in drought resistance in Arabidopsis occurs due to overexpression of flavonoid biosynthesis-related genes as it improves antioxidant activities mediated by anthocyanin. Similarly, in tobacco, overexpression of chalcone synthase leads to improved drought resistance through increased flavonoid content. Further it was also reported that overexpression of sweet potato cinnamate 4-hydroxylase (IbC4H) amplified phenolic content in cells conferring drought resistance in tobacco plants (Wang *et al*., 2017). Altered root morphology due to overexpression of the OsERF71 gene responsible for lignin biosynthesis were reported in transgenic plants (Lee *et al*., 2017).

Conclusion

Drought stress affects the crops at different growth stages both qualitatively and quantitatively. Significant understandings of the underlying genetic mechanisms and phyto-hormone regulations have although empowered workers in the development of moisture-stress resistant mechanisms. Identification and characterization of novel metabolites and their involvement in stress resistance, metabolic partitioning of photosynthates and overexpression of useful metabolites through genetic engineering, elucidation of drought resistant transcriptomic and metabolomic profiles and their subsequent interactive processes manifesting phenotypic adaptations could be explored which would further enable researchers in tackling drought stress. Hence manipulation and regulation of stress induced phyto-hormones would work towards development of drought resistance crops.

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