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Abscisic Acid (ABA) Mediated Drought Stress Tolerance in Plants

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Introduction:

Abscisic acid (ABA) is a plant hormone which regulates various processes involved in plant growth and development during stress period and helps plant in adaptation to adverse environmental conditions. Abscisic acid is well known naturally occurring growth inhibiting hormone in plants. Mostly synthesized in stem, leaf, fruit and in seed. Its function is antagonist to gibberelic acid. ABA is considered as chief stress hormone of plants, as it enhance the stress tolerance of plants to various kinds of environmental stresses. Environmental stresses such as heat stress, drought stress, cold stress, and salinity stress enhance the production of abscisic acid in plants, which helps in regulation of stomatal opening. ABA helps in conservation of transpirational loss of water through the efficient closure of stomata. Stress signals are converted to ABA and ABA triggers the activation of various physiological

and developmental processes enable plants to adapt condition. ABA starts signaling via ABA receptors present on plasma membrane of the plant cell and signal transmission is

done via downstream proteins such as kinases and phosphatases (Schroeder and Hagiwara, 1989).

This article focuses on the role of ABA in drought stress by analyzing the relationship between each ABA signaling component and these components in a complex interaction network.

Historical Aspect:

- In 1940s, scientists (Hamberg) isolated a substance from the mature Sycamore leaves; causing abscission of the leaves was called dormin.
- In the early 1960s, Philip Wareing confirmed that application of a dormin on a bud would induce dormancy.
- In 1963, Cornus and Addicot, isolated and identified that this compound stimulates abscission of cotton ball. He named that substance abscisin-II.
- In 1964 these three groups discovered the abscisin hormone and later on its name was changed to abscisic acid (ABA).

Chemical Structure:

ABA is a organic acid with 15-carbon sesquiterpene compound, composed of three isoprene residues, cyclohexane ring with keto, one hydroxyl group, a side chain with a terminal carboxylic group. The naturally occuring ABA is 2-cis-4-trans structure

(+).The **active form** of ABA is (+) ***cis* ABA**; (+)-2-*trans*-ABA also exists in plants and is active in some long-term ABA responses; it

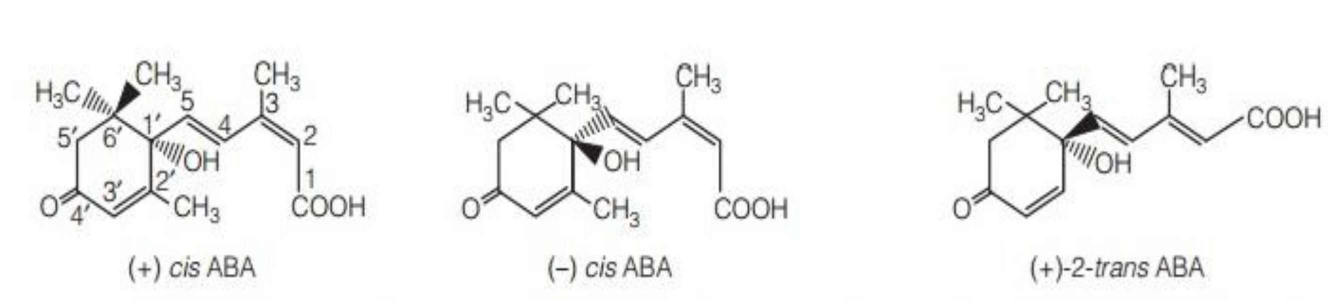

Fig.: Chemical structure of (+) and (-) forms of ABA. (+) *cis* ABA is active; (-) *cis* ABA is also active but very slow response. (+) *trans* ABA is inactive, but can be converted in to (+) *cis* ABA.

may be converted to the (+) *cis* form in tissues.

Site of Synthesis:

- ABA is ubiquitous in plants. It is also produced by some phytopathogenic fungi, bacteria and metazoans ranging from sea sponges to humans. It is mostly found in chloroplast.
- ABA has been detected in all major organs or living tissues from root to apical bud, phloem sap, xylem sap and in nector.
- ABA synthesis found in all types of cells having chloroplast or other plastids by maevlonic acid pathway.
- CIS-ABA is biologically activeform of ABA. Nearly all the naturally occurring ABA is in the cic form. It is inactivated by ABA-glucoside or O2 oxidation.

Biosynthesis of ABA:

- There are at least two biosynthetic pathways: plants synthesize ABA indirectly from carotenoids, whereas,
- in fungi it is directly from farnesly pyrophosphate
- Primarily ABA synthesis takes place in plastids except two steps in which xanthoxin is converted to ABA in cytosol.
- In higher plants ABA biosynthesis follow an indirect pathway which begins with IPP (isopentyl diphosphate), the biological isoprene unit.
- IPP is the precursor of all terpenoids as well as many plant hormones. A more specific pathway to ABA biosynthesis starts from the conversion of IPA (5C) to an intermediate compound beta-carotene which leads the synthesis of C40 xanthophyll zeaxanthin. zeaxanthin is further modified to

violaxanthin, in the presence of an enzyme zeaxanthin epoxidase (ZEP). Violaxanthin is converted to C40

- ABA can also be produced from a C_{15} precursor from farnesyl diphosphate and thus independent

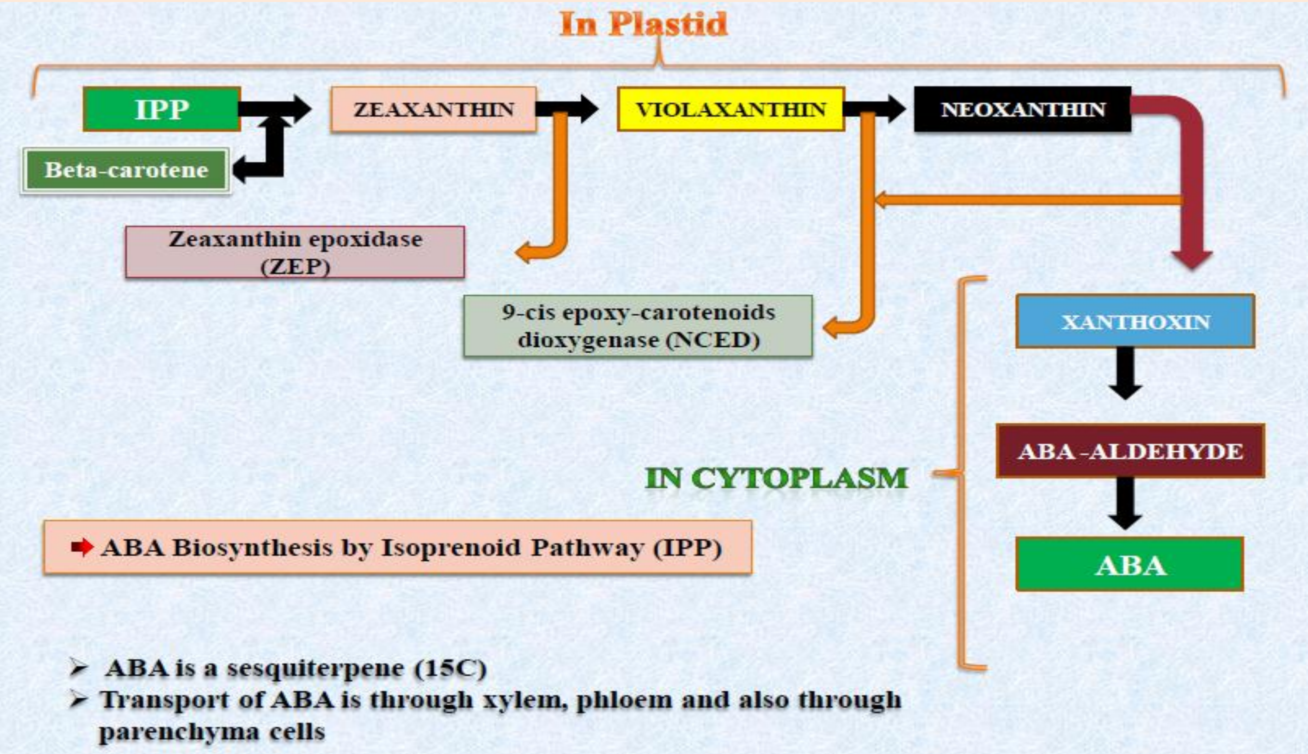

Fig. 1: Abscisic acid (ABA) Biosynthesis by Isoprenoid (IPP), Indirect Pathway

- compound, 9-cis neoxanthin. It is cleaved to form a C13 compound xanthoxal. This cleavage is catalyzed by 9-cis epoxy carotenoid dioxygenase (NCED) because it can cleave both violaxanthin and neoxanthin. Xanthoxal is further converted in to ABA via oxidative steps and ABA-aldehyde or xanthoxyic acid used as a intermediate substance.
- ABA is a degradation product of xanthophylls (especially of violaxanthin).

from the carotenoid/xanthophyll metabolism.

Transport of ABA in plant: Externally applied ABA would be distributed in all direction and its cell to cell transport would be rapid

- Naturally synthesized ABA has very slow cell to cell transport
- ABA synthesized in root cap transported to central vascular tissues.
- ABA is transported mostly in its free form
- Transported in conjugated form as ABA β-D-glucosyl ester.

Redistribution of ABA – pH gradient:

- At low pH protonated or un-dissociated from (ABAH)
- At high pH dissociated from (ABA-)

Role of ABA in Stomatal Closure: Stomata are present on the leaf surface of plants, play a greater role in uptake of CO2 from the environment and and loss of water from the plants. Each stomata is surrounded by two guard cells. Any change in the turgor pressure of the guard cell leads to stomatal opening and closing. Stomatal opening occurs when turgor pressure of guard cell increases and closes when guard cell turgor decreases. The combination of environmental stress signals and internal hormonal stimuli regulates the opening and closing of stomata. The complexity of the network of signaling pathways that control stomatal movement reflects the variety of variables to which guard cells respond. During water scarcity in plants there is a dramatic increase in level of ABA up to 50 times more in leaves than normal. It is highest level of hormone response to environmental stresses ever documented. The synthesis of ABA during drought stress takes place in roots and transported to the various parts of shoot. ABA is translocated to the leaves and in stomatal guard cells from the roots. ABA minimizes water loss through transpiration and adjusts osmotic balance of the cell by accumulating the osmotically active compounds that protect the cell from damage during drought. Mechanism of ABA action involved in stomatal closure during drought is described below:

Mechanism of ABA-Induced stomatal closure: ABA induced guard cell closure is mainly based on the key features of increased cytosolic calcium concentration Taylor and Burden, 1972). When sufficient ABA is accumulated around the guard cell

- ABA binds to the receptors present on plasma membrane of guard cells;
- Formation of reactive oxygen species (ROS) in the cell;
- The ROS activate the plasma membrane Ca+2 channels and stimulate the influx of Ca+2 in the guard cell from outside;
- ROS increase level of cyclic-ADP-ribose and IP3, which activate the calcium ion channels on the tonoplast membrane of the vacuoles due to that Ca+2 released from the vacuoles and cytosolic calcium ion concentration extremely increased;
- Rise in intracellular Ca+2 blocks K+ in channels on the plasma membrane and open Cl^- out (anion) channels, causing membrane depolarization;

- High cytosolic Ca+2 concentration inhibit proton pump due to that raise in intracellular pH, results in further depolarization of membrane;
- Membrane depolarization activates+ channels out;
- Stomata close;

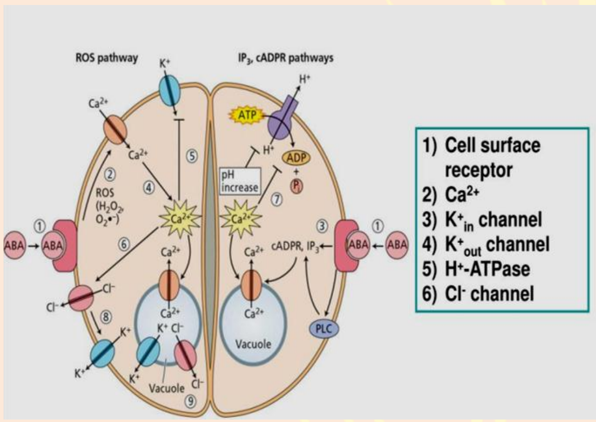

Fig. 2: Abscisic acid-induced stomatal closure, diagrammatic representation.

Role of ABA in Root Growth and Development under Drought Stress:

During drought stunted root growth and reduction in number of lateral rood has been reported in previous studies (Vander Weele et al., 2000; Deak & Malamy, 2005). In reaction to stress, ABA regulates root growth and architecture. In drought situations, the intermediate level of ABA drives root development to penetrate deeper and seek water. ABA is known to regulate the effect of osmotic stress on primary root length (Xiong et al., 2006). Ghassemian et al., (2000) reported that exogenous application of ABA on Arabidopsis in low concentration (0.1M) enhances primary root growth, whereas high concentration (> 1M) reduces root growth. Under moderate stress, blocking ABA production with fluridon was observed to rescue root elongation, showing that ABA is impeding root growth. The role of ABA in root growth depends on ABA concentration and may vary among plant species.

Conclusions and Future Perspectives:

Climatic conditions are changing day by day globally, that is the serious threat for food security and crop production. Among the abiotic stresses drought stress cause significant reduction in yield of crops. in response of the drought plants have adapted some mechanisms such as growth patterns, structural dynamics, reduction in water loss through transpiration via stomatal regulation, root proliferation, compatible solute accumulation, cellular osmotic adjustment etc., so that can be adapted to adverse environmental conditions. To fulfill the demand of food in such alarming climatic conditions it is needed to develop crop varieties that confer tolerance to drought stress and maintain their yield potential. Drought, as well as heat, salinity, and chilling conditions, are all controlled by the stress hormone ABA. Various physiological mechanisms regulated by ABA have been identified at the molecular level, however there is still room for more discoveries in the field. Indeed, the stress sensor's discoveries will help us better understand how a plant modifies its ABA accumulation in response to environmental stress. While certain putative sensors for cold, salt, and osmotic stress have been identified, the mechanism linking ABA responsiveness to environmental challenges is yet unknown.

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