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Abscisic Acid- A Stress Antagonist

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SUMMARY

Plant growth regulators play prominent role in the caliber of plants, a sessile organism to adopt to continuous changing environment by mediating their growth and development. In this regard abscisic acid is the most important stress responsive hormone. Abscisic acid, a plant hormone commonly called as stress hormone synthesized in almost all the cells that contain chloroplast and amyloplast. This plant hormone involved in many growth and developmental activities of a plant i.e., from seed germination to senescence that to mainly under stress conditions. Its action in regulation of plants developmental activities can be exploited by exogenously applying ABA's commercially available formulations.

INTRODUCTION

Plants must regulate its growth and development in order to respond to ever changing environment. This regulations are mediated by the plant hormones namely, auxin, cytokinin, gibberellic acid, ethylene, abscisic acid (ABA). So, it is substantially needed to understand the biosynthetic pathway, signaling pathway, role and cross talk between hormones. Abscisic acid is the plant growth regulator usually amalgamated with plant responses to stress conditions. It is 15 carbon week sesquiterpenoid having the molecular formula of $C_{15}H_{20}O_4$ and chemically 3-methyl 5-1′ (1′- hydroxy, 4′-oxy-2′, 6′ , 6′-trimethyl-2-cyclohexane-l-yl)-cis, trans-2,4-penta-dienoic acid (Fig. 1).

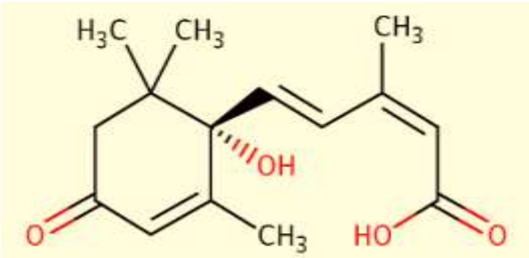


Fig. 1: Structure of ABA

Discovery

ABA was 1st identified by T Addicott and Larry A Davis in 1963 as a growth inhibitor in cotton fruit and leaves of sycamore trees. ABA is also called as stress hormone, inhibitor-B and dormin.

Forms of ABA

ABA occurs in 2 isomeric forms *i.e.*, *cis* and *trans* which are biologically active and inactive forms respectively and also both are interconvertible (Fig. 2). Because of asymmetric nature of 1st carbon atom S and R enantiomers are present, these are distinguished by their optical rotatory directions. In almost all plants ABA occurs in dextrorotatory cis form. Whereas, commercially available in a racemic mixture of equal amounts of S and R forms.

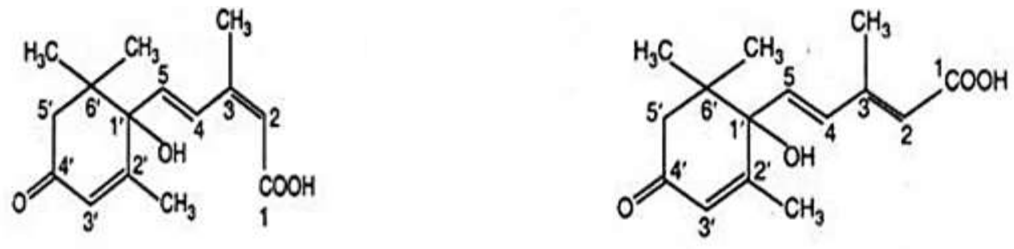
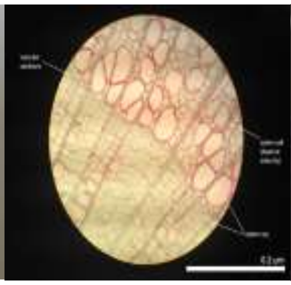


Fig. 2: *Cis* and *Trans* forms of ABA

Site of synthesis and precursors

ABA produced in most of the cells that contain chloroplasts and amyloplasts in plants besides it is also produced by phytopathogenic bacteria, fungi and metazoans. Violaxanthin and neoxanthin are the precursors of ABA in plants while farnesyl pyrophosphate in fungi.

Terminal buds



Vascular cambium

Roots

Seeds

Biosynthesis of ABA

ABA biosynthesis occurs in dual cell compartments (initiate in Plastids and completes in cytosol) and stored in vacuoles. In plastids of cell, zeaxathin will convert into 9-cis-violaxanthin and all-trans- neoxanthin in the presence of zeaxanthin epoxidase (ZEP), this step is interconvertible *i.e.*, 9-cis-violaxanthin and all-trans-neoxanthin (ABA-deficient 4[ABA4] should be present) can be converted into zeaxanthin in the presence of violaxanthin de-epoxidase. Next, from 9-cis-violaxanthin and all-trans- neoxanthin xanthoxin is formed in the presence of nine-cis-apoxicarotenoid-dioxygenase (NCED) and this will move to cytosol of the cell.

In cytosol, from xanthoxin abscisic aldehyde will form in the presence of ABA-deficient 2 (ABA 2). Further from abscisic aldehyde Abscisic acid is formed when ABA-deficient 3 (ABA3) and abscisic aldehyde oxidase is present. Formed ABA stored in vacuoles in the form of ABA-GA and used whenever it is needed (Fig. 3).

ABA signal pathway in plants

In the absence of ABA, group of 3 ABA receptors namely, pyrabactin resistance (PYR), Pyrabactin resistance1 like (PYL) and Regulatory component of ABA response (RCAR) and negative regulator *i.e.*, protein phosphatase 2C (PP2C) will not form complex because PP2C represses the activity of positive regulator (SnRK2) by dephosphorylating its kinase activating loop. Whereas in the presence of ABA, ABA receptors form complex with PP2C mediated by phosphorylation of SnRK2 (Fig. 4).

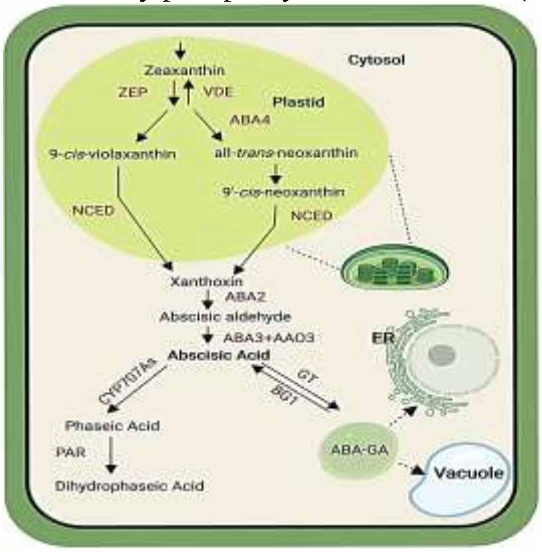


Fig. 3:Biosynthesis of ABA

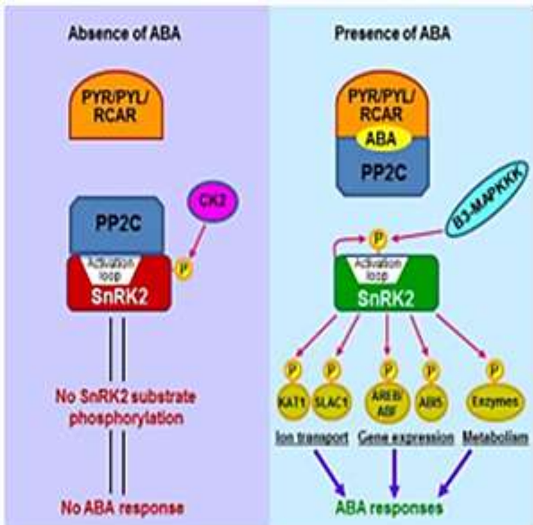


Fig. 4: ABA signaling pathway in plants

Endogenous and exogenous ABA concentration measurement done by

- HPLC (High Performance Liquid Chromatography)
- GC (Gas Chromatography)
- GC-MS (Gas Chromatography Mass Spectrometry)
- FRET probes (Forster Resonance Energy Transfer Probes)

Role of ABA in plant growth and development

- Stomatal regulation - Protecting cells from dehydration
- Gene regulation and expression
- Apical dominance

- Inhibit germination - Seed maturation, Promote seed and bud dormancy
- Response under environmental stress conditions
- Promote senescence
- Effect of ABA on root and shoot development
- Downregulates the photosynthesis process

Stomatal regulation - Protecting cells from dehydration

Under water stress conditions ABA released from the chloroplast of guard cells in stomata. ABA release detected by receptors of guard cells and induces ca^{2+} elevation inside the cell through influx of extracellular Ca^{2+} and release of Ca^{2+} from intracellularly. Elevated Ca^{2+} activates the anion channels that mediate release of anions (Cl^-) from guard cells. Anion efflux causes efflux of K^+ from guard cells due to depolarization by anions release and alkalization of the guard cells. Efflux of anions and K^+ from guard cells results in loss of guard cell turgor pressure as a result stomata closes under dehydration conditions (Fig. 5).

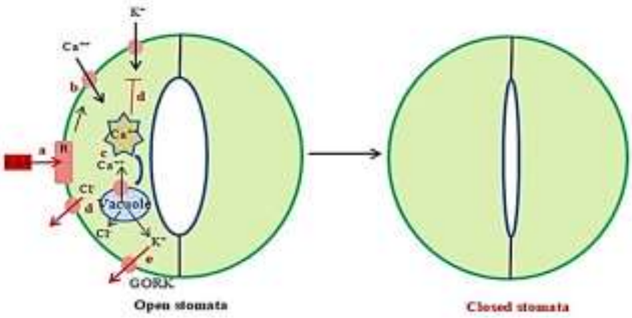


Fig. 5: ABA mediated stomatal regulation in plants

Gene expression

Since ABA plays an important role in different developmental processes and adaptive stress response to environmental stimuli in plants, endogenous ABA or the ABA analogues controls many drought responsive genes, ABA response factors (Transcription factors [TFs]) and regulate protein coding genes

Seed maturation and inhibition of seed germination

Both ABA (Abscisic acid) and GA(Gibberellic acid) biosynthesis takes place in plastids and they have common initial biosynthetic reactions. Hence plastids favour the synthesis of any one of these two hormones or else both hormones inhibit physiological effects of each other’s. This depends on phytochrome state, water stress and environmental conditions. For example, unfavorable environmental conditions like drought, salinity and cold stress results in ABA synthesis while phytochrome mediated high red: far red ratio mediates to synthesize gibberellic acid.

Seed maturation starts when seeds become physiologically independent of the parent plant, acquire trait like dormancy and deposits seed storage reserve. Seed dormancy is pivotal characteristic to prevent seed germination under harsh conditions. Hence in dormancy and germination ABA and GA plant hormones plays a prominent role (Fig. 6). During seed maturation ABA accumulation increases in seed which creates abscission layer, de-greening takes place and makes the seed desiccation tolerant and dormant. Similarly under favourable conditions *i.e.*, high red: far red ratio gibberellin synthesis will be more, this enhances amylase and protease synthesis which in turn ruptures testa and finally seed will germination

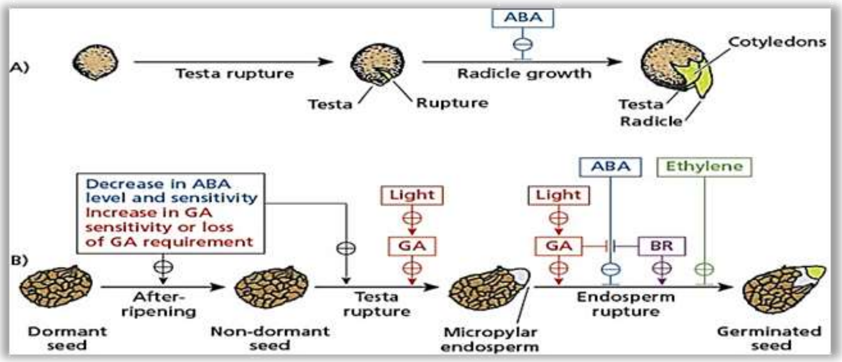


Fig. 6: Cross talk between ABA and GA in seeds

Bud dormancy

Abscisic acid mediates the conversion of apical meristem into a dormant bud by converting the newly developing leaves growing above the meristem into stiff bud scales which wrap the meristem closely and will protect buds from mechanical damage, drying out of bud during winter and prevents premature sprouting of buds.

ABA response during stress conditions

Under stress conditions, ABA synthesis level increases which makes ABA receptors to form complex with PP2C mediated by phosphorylation of SnRK2. This results in expression of stress related genes (Transcription factors) and other responses like stomatal closure.

Promote senescence

ABA initiate aging in leaves by increasing the synthesis of chlorophyllase enzyme, inducing high rate of respiration for short period of time, reducing photosynthesis and other anabolic processes like protein synthesis, activating ethylene synthesis and by influencing the formation of abscission layer

Effect of ABA on root and shoot development

ABA in the root inducts root elongation, inhibits lateral root formation and increases the root hydraulic conductivity. In some cases ABA also promotes stem cuttings *e.g.*, Ivy and Poinsettia. ABA in shoot reduces leaf mesophyll conductance and leaf hydraulic conductance, induce leaf senescence, controls leaf expansion, induces cuticular wax formation and inhibits shoot formation

Apical dominance

In maintaining apical dominance synergizes with auxin i.e., ABA moves up from the roots to the stem (opposite the flow of auxin) and suppresses the development of axillary buds which results in inhibition of branching

Downregulate the photosynthesis process

High ABA content enhances the cyclic electron flow around photosystem I, decreases the photosynthetic Co^2 assimilation and the amplitude of burning-induced electrical signals, decreased the activity of the H^+-ATP-ase in the plasma membrane and reduces the magnitude of photosynthetic responses.

CONCLUSION

Abscisic acid commonly known to help the plant to partially manage stress conditions like drought, salinity, cold stress and water stress. Apart from these it also involved in many biological functions like gene regulation, seed maturation, bud and seed dormancy, root and shoot growth and senescence.

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