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Salicylic Acid in Plant Growth and Development

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Salicylic acid is one among defense related phytohormones, and also a potential plant growth regulator. Exogenous application of SA has various effects on growth and development depending on the plant species, the stage of development, and the concentration of SA used. This hormone functions by triggering multiple physiological and metabolic pathways. It negatively interacts with jasmonic acid, ethylene and auxin hormones.

Introduction

Salicylic acid (o-hydroxybenzic acid) is an intermediate product of the phenylalanine metabolic pathway and is a derivative of cinnamic acid. Salicylic acid (SA) was initially discovered in willow bark in 1838 by Raffaele Piria, and its commercial synthetic production was begun in Germany in 1874 (Kaya *et al*., 2023). The SA serves as a signalling molecule in the immunological response of plants, regulating various aspects of plant development and growth including senescence, stomatal opening, cell growth, respiration, flowering, seed germination, thermogenesis, seedling development and disease resistance.

Inhibition of plant growth by salicylic acid

SA plays an important role in growth – defense tradeoff. Although treatment with low concentrations of SA stimulates growth in some plant species, high levels of SA almost always negatively impact plant growth. For example, application of 1 mmol of SA leads to severe growth retardation in *Arabidopsis* seedlings. Blocking SA hydroxylation also results in severe dwarfism due to SA overaccumulation. The reduced stature of some of the autoimmune mutants, such as *snc1* and *snc2-1D*, can be alleviated by blocking SA biosynthesis or SA signalling (Peng *et al*., 2021).

Salicylic acid and flowering time

In *Arabidopsis eds5* and *sid2* mutants and *NahG* transgenic plants, severely delayed flowering was observed. Consistently, the SA over accumulating mutant *sap and miz1domain-containing ligase1-2 (siz1-2)* displays an early flowering phenotype that can be suppressed by *NahG* expression. These findings suggest that SA is a positive regulator for floral transition. However, *win3-1*, a loss-of-function mutant of *PBS3/WIN3*, flowers earlier than wild type (Peng *et al*., 2021).

Salicylic acid and senescence

The SA levels in *Arabidopsis* leaf tissue increase during senescence and the transcript levels of several senescence-induced genes were reduced in *npr1* mutant and *NahG* transgenic plants. leaf senescence was delayed in *sid2* mutant and *NahG* transgenic plants. *S3H* knockout mutants accumulate high levels of SA and display precocious senescence, while transgenic lines overexpressing *S3H* exhibit reduced SA levels and delayed leaf senescence. Several SA-induced WRKY transcription factors were reported as positive regulators of senescence. The SA levels are elevated in *WRKY75* overexpression lines (Peng *et al*., 2021).

SA *v/s* auxin in plant growth

Growth inhibition by SA happens partly through the attenuation of auxin signalling. Transcriptome analysis revealed that the expression of 21 genes involved in auxin signalling is suppressed by treatment with the SA analogue BTH (benzothiadiazole). SA also suppresses auxin production indirectly by inhibiting CAT2 (catalase 2) activity (SA suppression of CAT2 results in increased H_2O_2 levels and subsequent sulfenylation of tryptophan synthetase β subunit 1, thus depleting the auxin biosynthetic precursor tryptophan) and negatively affects auxin transport by modulating the phosphorylation of PIN2 through inhibiting protein phosphatase 2A activity in *Arabidopsis.* Because auxin negatively impacts resistance to pathogens, SA-induced reduction of auxin signalling may play a critical role for plant immunity (Peng *et al*., 2021).

Salicylic acid *v/s* ethylene

SA and ethylene (ET) can play mutually inhibitory roles in defense response and in plant development (Kaya *et al*., 2023). ET regulates apical hook formation of etiolated seedlings through transcription factors ETHYLENE INSENSITIVE 3/EIN3-LIKE 1 (EIN3/EIL1), which activate the expression of a central regulator of hook development *HOOKLESS1* (*HLS1*). A recent study showed that the exogenous application of SA suppresses the apical hook formation and ET induced *HLS1* expression in a partially NPR1-dependent manner. Excessive ET accumulation leads to lower SA levels in *ethylene overproducer* 1 (Peng *et al*., 2021).

LSD1, EDS1 and PAD4 and SA

The EDS1 and PAD4 proteins function in resistance (R) gene-mediated and basal disease resistance. Lesion Simulating Disease 1 (LSD1), Enhanced Disease Susceptibility (EDS1) and Phytoalexin Deficient 4 (PAD4). The EDS1–PAD4 complex is also required for the accumulation of SA and systemic-acquired resistance (SAR). The *eds1* and *pad4* mutants accumulate less SA than the wild type during biotic stress. While, *Arabidopsis* plants overexpressing both EDS1 and PAD4 accumulate significantly more SA (Bernacki *et al*., 2019).

Rice: OsPAD4 is involved in JA-dependent defense responses. OsPAD4-silenced plants exhibit enhanced susceptibility to biotrophic pathogens associated with impaired accumulation of jasmonic acid (JA) and phytoalexin momilactone A (MOA). Moreover, exogenous JA application complemented the susceptibility phenotype of OsPAD4-silenced rice.

Vitis vinifera: The expression of VvEDS1 and VvEDL was up-regulated by pathogens and that of VvEDS1 additionally by SA.

Cotton: GbEDS1 expression is drastically increased in response to pathogens like *Verticillium dahlia.* Moreover, overexpression of GbEDS1 triggers higher SA and H2O2 production.

Triticum aestivum: The expression of TaLSD1 is up-regulated during interaction with the fungal pathogen, *Puccinia striiformis*, and in response to oxidative stress-generating compound methyl viologen (Bernacki *et al*., 2019).

Application of Salicylic Acid in Agricultural Production

1. Salicylic acid induces flowering
2. Promote high-quality and high-yield crops
3. External application of salicylic acid can increase the resistance and tolerance of crops to adversity
4. Improve the cold tolerance of crops
5. Improve fruit storage

6. Effect on fresh cut flowers
7. Induce the formation of female flowers

Conclusion

Salicylic acid plays critical roles in trade-offs between plant growth and defense. It plays crucial role in yield improvement, early flowering induction. Reduced SA levels can delay senescence, thus silencing or mutating related genes in biosynthesis or signalling can be exploited. The LSD1, EDS1 and PAD4 protein production can be regulated which further influence SA

References

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