Review Article

PLANT GROWTH REGULATORS IN ABIOTIC STRESS RESILIENCE OF VEGETABLE CROPS – A REVIEW

ABSTRACT

In recent decades, the global demand for vegetables has surged alongside population growth. However, biotic and abiotic stresses increasingly hinder seed germination, growthand yields. Plant growth regulators (PGRs) acting as chemical messengers are crucial in regulating plant development and responses to environmental stresses. Key phytohormones like abscisic acid, ethylene, salicylic acidandjasmonic acid play pivotal role in stress responses of vegetable crops. These hormones enable plants to sense and adapt to adverse conditions such as drought, salinityand extremities of temperatures. Through enzyme activation and hormone synthesis, plants enhance their resilience to stressors. The vital role of PGRs in mitigating stress impacts on vegetable crops, highlighting their potential in agricultural sustainability in future.

Keywords: PGR; Abiotic stress; Antioxidant enzymes; Growth stimulation; ROS

1.INTRODUCTION

Plants require essential resources such as sunlight, water, carbon dioxideand minerals for their growth and development. Insufficient availability of these inputs can induce stress in plants, leading to reduced growth and lower crop yields.Despite adverse environmental conditions, plants can experience stress and may adjust itself by slowing down their growth [1]. Given climate change and population growth, increasing agricultural productivity is critical, with a projected 70 per cent rise in output needed by mid-century to meet global demands amid significant climate variability impacting horticultural crop production [2].

Plants, being stationary, face challenges from environmental changes caused by human activities or seasonal shifts, including drought, waterlogging, salinity, extreme temperatures, presence of heavy metalsand solar radiation, all of which hinder optimal growth. These factors contribute to global decline in biomass and yields [3]. In severe conditions, different abiotic stresses can overlap, exacerbating their effects, such as the combined impact of salt stress and drought under extreme temperatures [4].

Both abiotic and biotic stresses being major constraints on agricultural productivity, salt, droughtand heat stress, particularly are widespread and crucial in affecting plant growth and development [5]. Conventional breeding methods, due to their complexity in developing stress-tolerant traits, often show limited efficacy, necessitating advancements to meet global food demands. Phytohormones have emerged as a promising alternative for cultivating productive and climate-resilient crops, leveraging plants' efficient sensing, signalingand response mechanisms to combat stress [6].

Phytohormones released by plants act as chemical messengers to regulate responses, growthand development under environmental stresses, especially in horticultural plants [7] [8]. They play a crucial role in coordinating various signal transduction pathways under abiotic stresses [9] [10], modulating both internal and external stimuli to induce significant changes in plant development. Research on phytohormones as signaling molecules in enhancing abiotic stress resistance has been extensively studied in horticultural plants [11] [12].

2. PLANT GROWTH REGULATOR (PGR)

“Plant growth regulators are generally defined as organic compounds, other than nutrients, that in small concentrations, affect the physiological processes of plants”.

The term "hormone" is derived from a Greek word meaning “to arouse or stimulate or enhance an activity".

At present, nine types of PHs have been identified including auxins, the first phytohormone discovered, salicylates (SA), ethylene (ET), cytokinins (CKs), gibberellins (GAs), brassinosteroids (BRs), jasmonates (JA), abscisic acid (ABA)andstrigolactones (SL), the last PHs to be discovered. Among these plant hormone (PH), ABA, SA, ETand JA have been recognized to have a central role in the plant’s responses to environmental stresses.

3. ABIOTIC STRESS

Abiotic stress refers to the detrimental impact of non-living factors on living organisms within a specific habitatincludes extreme temperatures (cold and heat), salinity, drought (lack of water), waterlogging (excess water)and radiation (high UV and visible light intensity) impact. Variables such as temperature, drought, nutrients, salinity, water availability, lightand flooding are critical for optimizing plant growth and development. These factors can cause significant yield losses in major crops, exacerbated by climate change, thereby jeopardizing food security. Abiotic stress alters the physiological, morphological, biochemicaland metabolic processes of plants, directly impacting their growth, developmentand productivity. Salinity, drought, heatand cold are particularly significant stressors affecting crop production, resulting in substantial yield reductions and up to 70 per cent decrease in biomass production[13] [14].

4. ROLE OF PLANT GROWTH REGULATOR IN ABIOTIC STRESS

Plant growth regulators (PGRs) play crucial rolein the physiological processes governing plant growth and development. The modulation of endogenous hormone levels in response to biotic and abiotic stresses significantly influences plant growth. Increasing the application of growth regulators can enhance yields and improve crop nutrition by mitigating stress impacts. PGRs contribute to stress tolerance by promoting seed germination, seedling growth, photosynthesis, root developmentand antioxidant enzyme activity, while reducing reactive oxygen species, malonaldehydeand electrolyte leakage. Recent research underscores the importance of various phytohormones like melatonin (MEL), Gamma-aminobutyric acid (GABA), jasmonic acid (JA), salicylic acid (SA), brassinosteroids (BRs)andstrigolactones (SLs) in enhancing abiotic stress resilience in horticultural plants. Besides their developmental roles, these hormones serve as pivotal mediators in plant responses to stress conditions. Phytohormones act as signaling molecules influencing diverse cellular and developmental processes. They can regulate multiple processes individually or synergistically, illustrating their versatality in plant biology [15] [16] [12].

In short, phytohormones such as ABA, SA, JAand ET, among others like auxins, gibberellins (GA) andcytokinins (CK), are pivotal in orchestrating plant defense mechanisms against both pathogens and abiotic stresses. ABA, for instance, is particularly crucial in conferring plant resilience to abiotic stresses such as drought, salinity, cold, heatand mechanical damage, by modulating various physiological processes [17].

5. ROLE OF PGRS IN ABIOTIC STRESS MANAGEMENT

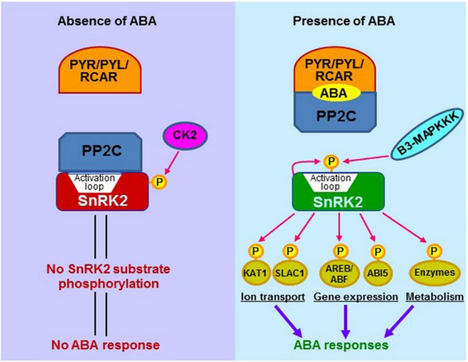
5.1 ABSCISIC ACID (ABA)

ABA, initially discovered in young cotton fruits 60 years ago, has since been identified in various plant species and mosses. Its functions include involvement in maturation processes, acquisition of desiccation toleranceand regulation of seed dormancy. Additionally, ABA plays a crucial role in plant development and responses to both biotic and abiotic stresses [18].

5.1.1 RELATIONSHIP BETWEEN ABA AND THE PLANT'S REACTION TO ABIOTIC STRESS

ABA serves as the primary hormone enabling plants to tolerate abiotic stresses, particularly salinity and drought. It is observed that salinity, droughtand low temperatures enhance the biosynthesis of ABA. Additionally, genes responsible for encoding essential enzymes in ABA biosynthesis may undergo catabolism once the stressful conditions subside [19]. During abiotic stress, including drought, low temperaturesand salinity, plant cells undergo dehydration. In response to stress, plants employ diverse strategies involving rapid physiological adjustments such as closing of stomata to prevent water loss, altering developmental patternsand undergoing biochemical changes in the expression and accumulation of various proteins associated with stress tolerance.

In higher plants, ABA plays a crucial role in governing multiple physiological processes, such as seed development and plant adaptation to various environmental stresses. In situations of water and saline stress, ABA facilitates the maintenance of water balance within the plant by regulating stomatal opening. During drought, there is an elevation in ABA concentrations within the leaves. This rise in ABA levels functions as a signaling mechanism, amplifying the initial stress signal and initiating subsequent signaling cascades [20]. Synthesis of ABA in roots and its translocation to leaves is a response mechanism to soil water scarcity. A well-established function of ABA is its ability to induce stomatal closure, thereby preventing desiccation [21]. The function of ABA extends even beyond salinity tolerance to various stressors, encompassing the regulation of water balance and osmotic stress tolerance in plants. Research suggests that ABA induces the expression of genes associated with abiotic stress through both dependent and independent pathways, as demonstrated by numerous experiments [22].



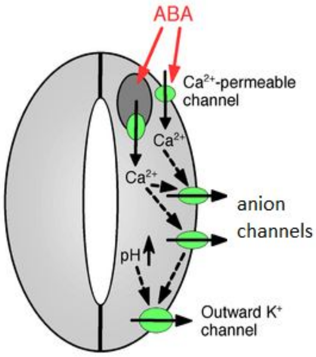


Fig.1.ABA Signalling mechanismFig.2. ABA effect on stomatal closure

5.2 ETHYLENE (ET)

Ethylene, existing in gaseous form, plays pivotal roles in various morpho-physiological processes crucial for plant development. These include triggering the triple response in germinating seeds, regulating flower development, initiating fruit ripeningand prompting plant responses to environmental cues. Additionally, ethylene governs a multitude of stress-related biochemical reactions in plants subjected to diverse abiotic stresses, including heat, drought, chilling, salinity, heavy metals, water-logging, flooding or submerged conditions [23]. An evident correlation exists between elevated levels of ethylene and exposure to freezing and cold stress in Arabidopsis[24]. The regulation of ethylene homeostasis proves essential for enhancing tolerance to suboptimal temperature stresses like chilling and freezing. Moreover, heightened ethylene levels contribute to salt stress tolerance, as observed in salt-tolerant Arabidopsis plants. ETIO1 (ethylene overproducer 1) plays a beneficial role in salt stress by positively influencing Na+/K+ balance and the production of reactive oxygen species (ROS) [25].

The biosynthesis of ET has been quantified in various plant tissues, wilting flowers and ripening fruits in plants exposed to abiotic stresses [26]. The underlying mechanism for ET biosynthesis gets initiated with S-Adenosyl methionine (SAM), which is the precursor of ET and is usually synthesized in large concentrations in various crops. An enzyme called 1- aminocyclopropane-1-carboxylic acid (ACC) synthase catalyzes the first chain reaction to convert SAM to ACCand methylthioadenosine (MTA), which subsequently gets recycled toL-methionine. Owing to this recycling, L-methionine levels remain unchanged even when ethylene biosynthesis is at its peak. Moreover, the ET biosynthesis pathway is affected by ACC synthase enzyme, which is extremely labile and tends to limit biosynthetic rate and rises proportionally as that of ethylene levels in tissues, flowersand fruits [27].

5.3 SALICYLIC ACID (SA)

Among phenolic endogenous growth regulators, salicylic acid is one of the most vital growth regulators and has been characterized in almost all plant species belonging to diverse groups. However, in plants subjected to salinity and osmotic stresses, the SA role remained somewhat ambiguous in various plant species depending on the intensity and duration of osmotic stress. The exogenous application of SA could alleviated the adverse effects of salinity [28]. During the 1960s, SA was synthesized from cinnamic acid (CA) by two biosynthetic pathways. One pathway involves a side chain of CA, which undergoes decarboxylation to produce benzoic acid, which is then subjected to 2-hydroxylation leading to the synthesis of SA in crops including tobacco. However, it postulated that some other enzymes involved in this pathway are still unknown. The second pathway of SA biosynthesis involves CA, which gets subjected to 2-hydroxylation, leading to ocoumaric acid production, which is subsequently decarboxylated to biosynthesize SA. Trans-cinnamate-4-hydroxylate enzyme is responsible for catalyzing this reaction. This pathway was first studied in seedlings of peas.

5.4 JASMONATES (JA)

Jasmonates are a broad group, which are covering various compounds, such as jasmonic acids (JAs), jasmonic acid methyl ester (JAME), precursor of the JAs; octadecanoid cis (+) 12 oxophytodienoic acid (OPDA), amino acid conjugates and metabolites such as 12-OH-JA and 11-OH-JA and often these compounds are involved in plant responses to biotic and abiotic stresses. Jasmonates are found throughout the plant body; however, shoot apex, root tips, immature fruits and young leaves like tender growing parts show remarkably high concentrations. The synthesizing pathway of JAs is said to be via the octadecanoid pathway, starting at linolenic acid and terminating at (+)-7-epi-JAs.

The major plant organs of biosynthesizing Jasmonates are leaves and roots, while chloroplasts and peroxisomes are the subcellular primary sites of JAs biosynthesis. Reports showed that development of the embryo and reproductive organs, determination of sex, seed germination and seedling development, root growth, fruit ripening, leaf movements and senescence, gravitropism, the formation of the trichome and tubers are mediated by JAs [29].

Further, signaling related to defense mechanisms of insects or pathogen are driven wounding is mediated by jasmonates. JAs have a crucial role in abiotic stress tolerance; thus, studies were focused on these compounds because of their significant protective capacity on plants against stress [30]. For example, JAs-mediated plant responses are shown against drought stress, ozone stress, UV-stress, salinity stress, cold stress [31] and temperature stress.

5.5 BRASSINOSTEROIDS

Brassinosteroids (BRs) are polyhydroxylated steroid PHs. They regulate several physiological and biochemical processes in the plant, such as cell elongation, cell division, photomorphogenesis, xylem differentiation, growth and reproduction [32]. The BRs exist in free and conjugated forms and nearly 69 and 5 conjugated and free BRs have been identified. The BRs are diverse in nature and biological activity. Among the BRs, brassinolide (BL) has been documented as the most active BR and it was isolated and purified from *Brassica napus* pollen [33]. The BRs are closely related to auxins, through the modulation of its transport, coordinating the tropic responses of plant organs and promoting lateral root primordial initiation during lateral root development. The endoplasmic reticulum most likely served as the site for BRs synthesis. The formation of a protein complex comprising enzymes (metabolon) to efficiently route the substrate to specified enzymes in a single biosynthetic pathway has been anticipated in plants only and BRs biosynthesis occurs through cyto-chromeP450 (CYP), a triterpenoid pathway [34].

Numerous studies have documented the abiotic stress tolerance in plants with exogenous application of BRs [35]. Nevertheless, the BRs need in minimal quantity like other PHs. Therefore, plant responses to exogenous BRs treatment are concentration-dependent. A high BR application rate is found to inhibit the plant growth, while the opposite is observed at lower concentrations. The abiotic stresses enhanced ROS generation leading to oxidative stress, while BRs help regulates the cellular ROS level under stressful environments.

For instance, 28-homobrassinolide application to *Brassica juncea* L. plants subjected to combined temperature and salt stress enhanced enzymatic antioxidant activities (SOD, CAT, APOX, DHAR and MDHAR) and ROS homeostasis [36]. Likewise, in *Lycopersicum esculentum*, BRs application ameliorated the supra optimal temperature-induced photosynthesis inhibition and augmented the carboxylation and activities of the antioxidant system [37].

5.6 POLYAMINES (PA)

Polyamines (PAs) are small aliphatic nitrogenous bases produced as a result of cellular metabolism. The PAs have no plant hormones, but due to their involvement in regulating several growth and development processes and responses to abiotic stress in plants, they have been proposed as a new category of plant growth regulators [38]. Initially, the ability of PAs to bind with anionic macromolecules was supposed to link with their biological functions, which lead to the consideration of PAs as polycations having distinctive structural roles. However, later may study demonstrated that PAs act as regulatory molecules in key cellular processes such as cell division, cell differentiation, DNA and protein synthesis and gene expression [39].

Furthermore, PAs are involved in various physiological processes in plants including embryogenesis, organogenesis, reproductive development, leaf senescence and fruit maturity. Several studies have reported the protective role of PAs against environmental stresses. Spermidine (Spd), spermine (Spm) and Putrescine (Put) are the major PAs in plants, while the role of cadaverine (Cad) and diamino propane (Dap) are less studied in plants. The PAs are present in conjugated (covalent and non-covalent bounded) or free form [40].

The main product of PAs biosynthetic pathway is Put, which serves as the precursor for Spm and Spd. In plants, Put biosynthesis occur in three different routes: via Arginine by arginine decarboxylase (ADC) (the most frequent route), via ornithine (Orn) by ornithine decarboxylase (ODC) and citrulline (Cit) by citrulline decarboxylase (CDC). The PAs catabolism is contingent on the action of diamine oxidase and PA oxidase and PAs metabolism is closely associated with several other metabolic pathways in plants. The H_2O_2 produced due to PA oxidation is involved in signal transduction and plant responses to biotic and environmental stresses [41].

The PA biosynthetic pathway is linked to ethylene synthesis, sharing the same precursor (S adenosyl methionine) and competing. Further, PAs metabolism is closely associated with nitric oxide generation, which triggers a signal transduction process related to plant growth. The distribution of PAs is organ and tissue-specific in plants. For instance, Put is the most abundant PA found in leaves, while the higher level of Spd is present in other plant organs. Polyamines are implied in response to different abiotic stresses. Generally, transgenic plants overexpressing PA biosynthetic enzymes, such as spermidinesynthase, argininedecarboxylaseand S-adenosylmethionine synthetase, showed the protective roles of polyamines under abiotic stress conditions. Moreover, exogenous application of PAs showed increased stress tolerance in several plant species [42].

6. CONCLUSION

Use of phytohormones have emerged as a pivotal technique in modern agricultural practices for managing stress in plants. They play a crucial role in protecting plants from a range of abiotic stresses such as floods, droughts and salinity by enhancing antioxidant enzyme activity, reducing oxidative damage and promoting overall plant development. This application of phytohormones not only ensures the sustainability of crop production but also enhances the resilience of horticultural crops to adverse environmental conditions.

In flood-prone areas, where excessive water can suffocate roots and disrupt normal physiological processes, phytohormones help plants maintain vigour by regulating growth and development. Similarly, in drought-affected regions, phytohormones mitigate the impact of water scarcity by enhancing water use efficiency and supporting root growth, thereby improving drought tolerance.

Saline soils, which restrict water uptake and cause ion toxicity, pose another significant challenge for crop productivity. Phytohormones aid in regulating ion transport and maintaining cellular homeostasis, enabling plants to thrive in saline environments. They also contribute to the harmonization of the germination process, crucial for initiating plant growth cycles under stress conditions. By enhancing seed viability and breaking dormancy, phytohormones ensure a more synchronized and successful germination, which is particularly beneficial in unpredictable climates.

The utilization of phytohormones in agriculture underscores their multifaceted role beyond mere growth regulation. They act as signaling molecules that orchestrate adaptive responses in plants, ensuring survival and productivity under adverse conditions. Through targeted application and research, scientists continue to explore the specific mechanisms by which phytohormones can be optimized for different crops and environmental stresses, aiming to enhance global food security and sustainability.

In conclusion, phytohormones represent a promising avenue for sustainable agriculture, offering practical solutions to mitigate the impact of abiotic stresses and support robust crop production in challenging environments worldwide.

7. REFERENCE

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