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An Update on Role of Salicylic Acid Alleviating High Temperature Stress in Plants

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Throughout their lifecycles, plants encounter a diverse array of environmental challenges. Abiotic stressors, including water scarcity, extreme temperatures, salinity, and toxic metal ions, can significantly impact plant health. Climate change exacerbates these stresses by increasing the frequency of severe weather events. Plants have evolved complex adaptive mechanisms to cope with such challenges. They can adjust their development in response to environmental cues mediated by plant hormones. High temperatures have profound and deleterious effects on various aspects of plant physiology, development, and overall well-being (Shaukat et al., 2022). With ongoing global temperature increases due to climate change, understanding these effects is critical for agricultural sustainability, ecosystem health, and food security. Elevated temperatures can impair photosynthesis, the process by which plants convert sunlight into energy and carbohydrates. Excessive heat can damage the photosynthetic machinery, resulting in reduced carbon dioxide uptake and diminished crop yields. Moreover, plants exhibit heightened respiration rates at higher temperatures. While respiration is crucial for energy production, excessive respiratory activity can deplete the plant's energy reserves, reducing resources available for growth and reproduction (Khalid et al., 2023). Furthermore, high temperatures can exacerbate water stress in plants by increasing evapotranspiration rates, leading to water loss surpassing the plant's ability to uptake water from the soil. This can result in wilting, leaf damage, and dehydration. The negative impacts of high temperatures on plant health, growth, and reproduction can have widespread consequences, disrupting ecosystems, agriculture, and food production systems. Therefore, it is imperative to address climate change and implement strategies to mitigate its adverse effects on plant life (Kaya et al., 2023).

In challenging conditions, the signaling pathways of phytohormones interact with metabolites to regulate plant growth and development, playing a crucial role in sensing and adapting to abiotic stresses. While research on the effects of phytohormones on heat stress is limited, there is substantial high-quality information available. Various phytohormones such as auxin, abscisic acid (ABA), gibberellic acid (GA), cytokinins (CKs), jasmonic acid (JA), salicylic acid (SA), ethylene, brassinosteroids (BRs), nitric oxide (NO), and polyamines (PAs) play a critical role in mitigating heat stress by regulating plant growth and development (Saeed et al., 2023). Plants respond to heat stress by activating complex and interconnected signaling pathways, allowing them to alleviate the negative effects of heat stress. Molecularly controlled processes enable plants to quickly adapt to heat stress conditions. Plants growing under high temperatures can benefit from the external application of osmoprotectants, signalling molecules, nutrients, and other compounds (Khan et al., 2023). Salicylic acid (SA) plays a crucial role in helping plants cope with high-temperature stress by activating various physiological, biochemical, and molecular responses. Traditionally known for its role in plant defense against pathogens, recent studies have revealed its significance in enhancing plant tolerance to high temperatures (Jahan et al., 2019).

A brief history of salicylic acid

In the fourth century B.C., it was recommended that pregnant women chew on willow leaves for pain relief (Raskin 1992). The therapeutic effects of willow leaves and bark were not researched until the middle of the 1700s, despite its widespread use as a folk treatment of pain. This study was conducted by Reverend Edward Stone in Oxford, England. Extracting and purifying a little amount of a yellowish material, Johann A. Buchner, a German chemist, named salicin, in 1828. Raffaele Piria, an

Italian chemist, separated salicin into a sugar and an aromatic molecule that he termed acidesalicylice or salicylic acid later that year (1838). Large-scale manufacture of SA for medical usage began when Hermann Kolbe and his colleagues performed the first chemical synthesis of SA in 1859. Its widespread use was hampered, however, by its unpleasant flavour and long-term negative effects. Later, Bayer pharmaceutical firm worker Felix Hoffmann discovered that SA could be acetylated to create a molecule with improved tolerability that retained all of the drug's positive properties. In 1899, acetyl salicylic acid was marketed as a pain reliever under the brand name aspirin.

SA biosynthesis and metabolism with pathways (IC & PAL pathways)

Salicylic acid (SA) is a phytohormone and signalling molecule in plants that plays a crucial role in various physiological processes, including defense against biotic and abiotic stress. SA biosynthesis and metabolism involve several pathways, with the two major pathways being the isochorismate (IC) pathway and the phenylalanine ammonia-lyase (PAL) pathway. The IC pathway is the primary biosynthetic route for SA in plants, especially during pathogen infection and stress responses. The PAL pathway is a minor route for SA biosynthesis but can contribute to SA production under certain conditions. Salicylic acid biosynthesis and metabolism involve the IC and PAL pathways, with the IC pathway being the primary route for SA production. SA serves as a central signalling molecule in plant defense against biotic stress and plays a role in various physiological processes, making it a critical component of plant immunity and stress responses (Lefevere et al., 2020).

Role of salicylic acid in mitigation of high temperatures stress in plants

Salicylic acid (SA) plays a significant role in the mitigation of high-temperature stress in plants by activating various physiological, biochemical, and molecular responses. SA, a naturally occurring phytohormone, has traditionally been associated with plant defense against pathogens. However, recent research has shown that it also contributes to enhancing plant thermotolerance (Sangwan et al., 2022). High temperatures can lead to the overproduction of reactive oxygen species (ROS) in plant cells, causing oxidative damage to cellular components. SA helps counteract this by inducing the expression of antioxidant enzymes like superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD). These enzymes scavenge ROS, reducing oxidative stress and preventing cellular damage.SA can upregulate the expression of heat shock proteins (HSPs), which are essential for protecting cells from heat-induced damage (Kumar et al., 2015). HSPs help refold denatured proteins and maintain cellular protein homeostasis under heat stress conditions.SA induces the accumulation of Osmo protectants such as proline and soluble sugars. These compounds help maintain cellular turgor and water balance under heat stress. They also act as osmolytes, protecting cellular proteins and membranes from denaturation.SA acts as a signalling molecule that triggers a complex network of pathways involved in plant defense against stress. It crosstalks with other phytohormones like abscisic acid (ABA) and jasmonic acid (JA) to fine-tune plant responses to heat stress (Raza et al., 2023) (Fig. 1). Salicylic acid serves as a crucial component of the plant's defense and acclimation mechanisms against high-temperature stress. Its ability to regulate antioxidant systems, induce protective proteins, maintain membrane stability, and activate stress-responsive genes contributes to enhancing plant thermotolerance. Understanding and harnessing the role of SA in mitigating heat stress has significant implications for agriculture and environmental sustainability in the context of climate change (Choudhary et al., 2024).

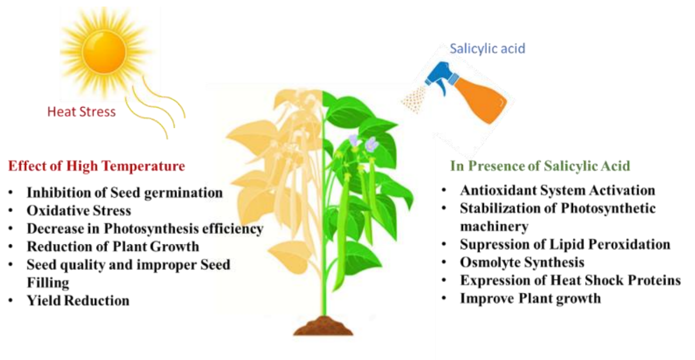

Figure 1. Effect of high temperature in plants and its alleviation through the foliar application of salicylic acid

Conclusion

Salicylic acid emerges as a vital regulator in the intricate network of plant responses to high-temperature stress. Harnessing the full potential of SA holds promise for the development of sustainable agricultural practices and the mitigation of heat stress-related crop losses, thus ensuring global food security and environmental sustainability in the face of a changing climate. SA, a natural phytohormone, has emerged as a key player in enhancing plant resilience to various abiotic stresses, including heat stress. Through its modulation of physiological, biochemical, and molecular processes, SA acts as a signaling molecule, orchestrating a complex network of pathways to enhance plant thermotolerance. Its interactions with other signalling molecules further fine-tune heat stress responses in plants, contributing to their ability to withstand high temperatures.

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