Halophytes and Their Multifaceted Approaches to Salt Stress Tolerance

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Introduction

Plants face many environmental abiotic stresses. These stresses induce a wide variety of survival and tolerance responses, including enhanced accumulation of osmolytes, reduced photosynthesis, closure of stomata, and induction of stress-responsive genes. Due to the loss of arable land and decreased agricultural production, salinity is a key abiotic stressor that has been linked to substantial economic effects. Globally, rising salt levels harm around 950 million hectares of land (Kumar and Sharma, 2020). The majority of plants are vulnerable to salt stress, and salinity can impede plant growth by inducing oxidative and osmotic stress as well as ionic toxicity. Additionally, exposure to salt can cause the production of reactive oxygen species (ROS), which can harm lipids, proteins, and DNA. Furthermore, chloroplast structure can be adversely affected by salt stress, which can result in reductions in photosynthesis and chlorophyll levels.

Halophytes, or salt-tolerant plants, possess the remarkable ability to thrive in environments with high levels of salinity. The study of these plants provides valuable insights into the essential adaptations necessary for survival in such harsh conditions. These adaptations include the secretion of salt through specialized glands, the regulation of cellular ion balance and osmotic pressure, the detoxification of harmful reactive oxygen species, and changes in membrane composition. Researchers have isolated salt-responsive genes from halophytes and introduced them into non-salt tolerant plants through targeted transgenic techniques to investigate the mechanisms underlying salt tolerance. (Xiaoqian Meng et al.,2018, Mann et al.,2023).

Cushman (2001) distinguishes between facultative, obligatory, and habitat-indifferent halophytes using Eco physiological traits. Although they can tolerate a saline environment, habitat-indifferent halophytes are indistinguishable from their natural habitat and typically prefer to dwell in a soil devoid of salt. By combining anatomical data with ecological parameters (salinity), Grigore and Toma (2010) have established a new form of classification of halophytes: meso-halophytes (irreversible and reversible) and extreme-halophytes (irreversible and reversible). Extreme halophytes that thrive only in saline environments are well-adapted extreme halophytes. Moreover, these halophytes may have reversible or irreversible habitats (Mishra and Tanna.,2017).

Molecular, physiological, biochemical and morphological mechanisms that allow halophytes to adapt to saline conditions

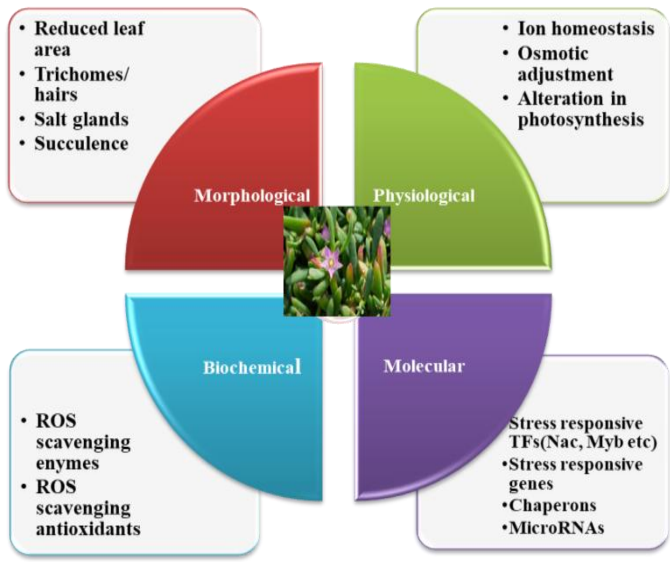

Fig. 1 Overview of Mechanisms Operating in Halophytes under Salinity Stress Conditions

1. **Ion Exclusion**: Halophytes have defenses against salt that prevent it from getting into their roots or reduce its amount of entrance into the shoot system. In the root cells, this may entail particular ion transporters and channels that actively pump sodium ions out or that preferentially take up other ions, such as potassium, in place of sodium. Halophytes can stave off injury from salt by keeping their tissues' sodium ion concentrations lower.

2. **Salt Sequestration**: Within their cells, several halophytes have the ability to separate salt into vacuoles. Active transport of sodium ions into vacuoles, where they are kept apart from the cytoplasm and essential organelles, is known as vacuolar sequestration. This lessens the harmful

effects of sodium ions and helps to maintain lower cytoplasmic concentrations of them.

3. **Osmotic Adjustment**: Halophytes often accumulate compatible solutes such as proline, glycine betaine, and various sugars in their cells in response to salt stress. These compatible solutes help in maintaining cellular osmotic potential, which allows the plant to retain water and prevent dehydration in saline conditions.

4. **Antioxidant Defense Mechanisms**: Reactive oxygen species (ROS) produced by high salt concentrations can cause oxidative stress in plant cells. In addition to non-enzymatic antioxidants like ascorbate and glutathione, halophytes have effective antioxidant defense systems that include enzymes like superoxide dismutase, catalase, and peroxidases. These antioxidants prevent oxidative damage to biological components by scavenging reactive oxygen species (ROS).

5. **Modulation of gene expression**: Halophytes regulate the expression of certain genes involved in salt tolerance. Transcription factors such as the DREB (dehydration-responsive element-binding) and MYB (myeloblastosis) families play a crucial role in the activation of stress-responsive genes. These genes encode proteins involved in ion transport, osmotic adjustment and antioxidant defense, which improves the plant's ability to tolerate salt stress.

6. **Morphological adaptations**: Some halophytes exhibit morphological adaptations such as reduced leaf surface area, succulence and salt glands. A reduced leaf surface helps to minimize water loss through transpiration, while succulence enables water retention. Salt glands are specialized structures that actively excrete excess salt from the plant tissue, thus reducing salt accumulation.

Conclusion

Halophytes are plants that can withstand salinity and have evolved various molecular, morphological and physiochemical adaptations to cope with the extreme harsh environment. Therefore, halophytes can serve as one of the potential sources to develop salt tolerant crop varieties in near future.

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