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Effect of Salinity on Grapevines (*Vitis vinifera* L.): Physiological, Biochemical, and Agronomic Implications

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Grapevines (*Vitis vinifera* L.) are widely cultivated for fresh consumption and wine production, contributing significantly to the global horticulture industry. However, soil salinity has emerged as a critical constraint in viticulture, especially in regions where irrigation with saline water is common. Salinity stress arises primarily from excessive accumulation of soluble salts such as sodium chloride (NaCl) in the root zone, leading to adverse effects on plant growth and productivity. The sensitivity of grapevines to salinity varies depending on cultivar, rootstock, and environmental conditions, but most commercial varieties are considered moderately sensitive.

Mechanisms of Salinity Stress in Grapevines

Osmotic Stress

Salinity reduces the soil water potential, making it difficult for roots to absorb water. This results in physiological drought conditions, even when soil moisture is adequate. Reduced water uptake leads to decreased cell expansion and stomatal closure, ultimately limiting photosynthesis.

Ion Toxicity

Excessive accumulation of sodium (Na^+) and chloride (Cl^-) ions in plant tissues disrupts cellular homeostasis. Chloride toxicity is particularly significant in grapevines, causing leaf burn, necrosis, and premature leaf senescence. High Na^+ levels interfere with potassium (K^+) uptake, disrupting enzymatic processes.

Nutrient Imbalance

Salinity affects the uptake and distribution of essential nutrients such as nitrogen, potassium, calcium, and magnesium. Competition between Na^+ and K^+ ions leads to reduced nutrient availability, affecting plant metabolism and growth.

Physiological Effects of Salinity

Salinity stress significantly alters grapevine physiology. One of the primary responses is stomatal closure, which reduces transpiration and carbon dioxide uptake, thereby limiting photosynthetic activity. Chlorophyll degradation is also observed, leading to reduced photosynthetic efficiency. Additionally, salinity impairs water relations by decreasing relative water content and turgor pressure in plant cells. These changes collectively result in reduced vegetative growth, including shorter shoots, smaller leaves, and decreased biomass accumulation.

Biochemical Responses

Grapevines exhibit several biochemical adaptations under salinity stress. The accumulation of osmolytes such as proline, glycine betaine, and soluble sugars helps maintain osmotic balance. Antioxidant defense systems are activated to counteract oxidative stress caused by reactive oxygen species (ROS). Enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) play a crucial role in protecting cellular structures. However,

prolonged stress can overwhelm these defense mechanisms, leading to lipid peroxidation and cellular damage.

Impact on Yield and Fruit Quality

Salinity adversely affects both yield and fruit quality in grapevines. Yield reduction occurs due to decreased berry size, cluster weight, and number of clusters per vine. Fruit composition is also altered; while moderate salinity may increase sugar concentration due to reduced berry size, excessive salinity negatively impacts flavor, acidity, and overall fruit quality. High chloride accumulation in berries can affect wine quality, making salinity management critical in viticulture.

Rootstock and Cultivar Variability

The tolerance of grapevines to salinity varies significantly among rootstocks and cultivars. Salt-tolerant rootstocks such as 1103 Paulsen and Ramsey exhibit better ion exclusion and water-use efficiency. These rootstocks restrict the uptake of Na^+ and Cl^- , thereby protecting the scion. Selection of appropriate rootstocks is one of the most effective strategies for managing salinity in vineyards.

Mitigation Strategies

Several agronomic and technological approaches can mitigate the effects of salinity on grapevines:

- Use of salt-tolerant rootstocks to limit ion uptake
- Efficient irrigation management, including drip irrigation and leaching practices
- Soil amendments such as gypsum to reduce sodium levels
- Application of biostimulants and nanofertilizers to enhance stress tolerance
- Foliar nutrient sprays to correct deficiencies

Future Perspectives

Future research should focus on developing salt-tolerant grapevine cultivars through breeding and genetic engineering. Advances in molecular biology and omics technologies can provide insights into stress tolerance mechanisms. Additionally, precision agriculture tools and nanotechnology-based inputs offer promising solutions for managing salinity stress in vineyards.

Conclusion

Salinity is a major limiting factor in grapevine cultivation, affecting plant growth, physiology, and fruit quality. Understanding the mechanisms of salinity stress and adopting appropriate management strategies are essential for sustainable viticulture. The integration of traditional practices with modern technologies can significantly enhance grapevine resilience under saline conditions.