in photosynthetic rate under 75 and 150 mM NaCl, with a more pronounced decline at 150 mM. Under such conditions, CO_2 diffusion into the leaf becomes restricted, while photochemical processes within mesophyll cells may also be impaired. Therefore, the decline in photosynthesis cannot be attributed solely to stomatal closure.

Salinity stress also disrupts electron transport in chloroplasts, mitochondria, and peroxisomes. When the production of O_2^- and H_2O_2 exceeds the capacity of antioxidant scavenging systems, lipid peroxidation occurs. Increased malondialdehyde (MDA) content and electrolyte leakage are common consequences. Comparisons among pepper genotypes further indicate that salt-tolerant materials generally maintain stronger activities of antioxidant enzymes such as superoxide dismutase (SOD) and catalase (CAT) (Zhang et al., 2022). However, this process is not entirely detrimental, because moderate levels of reactive oxygen species (ROS) also function as signaling molecules under stress. The major problem arises when ROS remain excessively elevated for prolonged periods.

2.3 Physiological roles of silicon under salinity stress

One of the most direct effects of Si in alleviating salinity damage is an improvement in plant water status. Previous studies suggest that Si may not only reduce nonproductive water loss, but also influence root hydraulic conductance and aquaporin activity. Rios et al. (2017) proposed that Si-mediated regulation of aquaporins can enhance root water uptake under salinity stress. Corresponding responses have also been observed in pepper. Application of 2 mM Si significantly improved leaf water potential in salt-stressed plants, and this improvement occurred together with recovery in stomatal conductance and dry matter accumulation.

Another important role of Si involves the antioxidant system and ion homeostasis. Si does not directly "eliminate" all free radicals, but it can modify enzymatic scavenging capacity and reduce the sustained generation of ROS. At the same time, Abdelaal et al. (2020) observed reduced Na^+ uptake and improved K^+ retention following Si application. In sweet pepper treated with foliar Si, tissue Na content decreased from 0.40% to 0.19% under 1500 ppm NaCl and from 0.48% to 0.30% under 3 000 ppm NaCl, corresponding to reductions of approximately 52.5% and 37.5%, respectively. These changes are physiologically substantial.

In intact plants, these processes do not operate independently (Figure 1). Improved water status can alter stomatal behavior, while enhanced photosynthesis provides additional carbon skeletons and metabolic energy. Reduced ionic toxicity may in turn lower the generation of ROS. More recent studies have further incorporated abscisic acid (ABA), aquaporins, secondary metabolism, and gene expression into this regulatory network. Liu et al. (2024) showed that Si can improve root hydraulic conductance through effects on ABA biosynthesis and aquaporin expression. However, direct molecular evidence in pepper remains limited at present. Mechanistic findings from other plant species can therefore provide useful references, but they should not be directly extrapolated to pepper without further validation.

3 Effects of Exogenous Silicon on Pepper Growth under Salinity Stress

3.1 Shoot growth responses

Under salinity stress, pepper plants generally show reduced plant height, while the formation of new leaves and leaf area expansion are also restricted. However, plant height does not always respond to Si application with a consistent increase. Manivannan et al. (2016) reported that, under 50 mM NaCl, shoot length increased from 6.80 cm in the salt-stressed treatment to 13.40 cm following Si application, representing an increase of approximately 97%. In contrast, Badem and Söylemez (2022) found that under 100 mM NaCl, Si increased stem diameter and dry weight without a corresponding increase in plant height; some treatments even showed reductions in plant height and root length. These findings indicate that taller plants do not necessarily reflect better growth. In some cases, Si may primarily alter plant compactness and dry matter accumulation rather than promoting stem elongation.

Biomass appears to show a more consistent positive response than plant height. In 'Bugwang', Si application under salinity stress increased fresh weight from 0.91 to 2.11 g, corresponding to an increase of approximately