3.3 Biomass allocation and growth recovery

The root-to-shoot ratio does not necessarily increase consistently following Si application. A simple explanation is that both shoots and roots may recover, but at different rates. Under mild to moderate salinity stress, photosynthetic recovery may occur relatively rapidly, allowing a greater proportion of newly assimilated carbon to be allocated to leaves and stems. Under more severe salinity stress, maintaining root water uptake and ion exclusion becomes increasingly important. In a combined Si-K experiment, Bushra et al. (2025) reported that under a salinity level of 12 dS/m, the combined treatment increased root and shoot biomass by approximately 53% and 55%, respectively, compared with the corresponding control. This result indicates that the nutritional background can substantially modify the biomass response to Si. However, because potassium was applied together with Si, the entire increase cannot be attributed to Si alone.

The relative effect of Si often becomes more evident under moderate to relatively severe salinity stress, although excessively high salinity may eventually impose a biological limit on recovery. Altuntas et al. (2018) found that the sensitive cultivar 'Demre' showed a relatively pronounced improvement at 75 mM NaCl, whereas the salt-tolerant cultivar 'Karaisali' still responded well at 150 mM NaCl. Such crossover responses indicate that salinity intensity cannot be interpreted independently of genotype. In other words, a given Si dose does not produce a fixed percentage of growth recovery across different genotypes and salinity levels.

4 Effects of Exogenous Silicon on Photosynthesis and Water Relations in Pepper

4.1 Photosynthetic pigment responses

Chlorophyll is a relatively sensitive indicator of salinity stress. In a nanosilicon experiment using 'Mızrak' pepper, application of 1 mM nanosilicon (nSi) under 100 mM NaCl increased chlorophyll a from 1.672 to 2.171, corresponding to an increase of approximately 29.8%. Under 150 mM NaCl, chlorophyll a increased from 1.534 to 1.921, or by about 25.2% (Kusvuran et al., 2024). The recovery of chlorophyll b was even more pronounced, with increases of approximately 56.8% and 42.7% under 100 and 150 mM NaCl, respectively. These results suggest that the effects of Si are not limited to maintaining leaf water status, but also involve protection of the photosynthetic pigment system. Carotenoids function both as accessory pigments and as components of the chloroplast antioxidant system. The same study reported that 1 mM nSi increased carotenoid content by approximately 34% under 100 mM NaCl and by about 61% under 150 mM NaCl.

However, higher nanoparticle concentrations do not necessarily produce greater benefits. Overall, 0.5-1 mM nSi performed better than 2-3 mM. González-García et al. (2021) investigated sweet pepper (*Capsicum annuum* 'Kitrino') under 0, 25, and 50 mM NaCl and applied SiO_2 nanoparticles at 200 and 1 000 mg/L. Exposure to 50 mM NaCl alone reduced leaf chlorophyll a by approximately 54% relative to the non-saline control. At this salinity level, 200 mg/L SiO_2 increased chlorophyll a and raised total chlorophyll by approximately 52%, whereas 1 000 mg/L SiO_2 failed to improve chlorophyll a. In the fruit, the combination of 50 mM NaCl and 200 mg/L SiO_2 increased flavonoids by approximately 156%, yellow carotenoids by about 45%, and phenylalanine ammonia-lyase (PAL) activity by approximately 59%. In contrast, the 1 000 mg/L treatment did not show comparable advantages for these traits.

4.2 Gas exchange and photosynthetic efficiency

Altuntas et al. (2018) provided one of the more comprehensive datasets on gas exchange responses in pepper. Under 75 and 150 mM NaCl, application of 2 mM Si increased net photosynthetic rate in 'Karaisali' by 11.5% and 14.6%, respectively, and in 'Demre' by 21.8% and 11.1%, respectively. Across these four independent salinity-genotype comparisons, the median increase was approximately 13.0%. Stomatal conductance increased by about 20% in both cultivars under 75 mM NaCl, whereas under 150 mM NaCl the recovery was greater in the sensitive genotype.

The increase in transpiration following Si application does not necessarily mean that plants were "wasting" more water. Under salinity stress, excessive stomatal closure restricts both water loss and CO_2 entry. Partial reopening of stomata following Si treatment can therefore increase transpiration and CO_2 diffusion simultaneously. Available results indicate that Si increased transpiration rate in salt-stressed pepper by approximately 30%-55%,