nitric oxide (NO) application. Experimental protocols differ substantially in treatment frequency, leaf developmental stage, and the timing of stress initiation. These differences are likely to be important sources of heterogeneity in pooled effect estimates.

7.2 Salinity intensity and duration

Under mild salinity stress, endogenous defense systems may still retain sufficient capacity, and the absolute improvement following Si application can therefore be relatively small. As stress reaches moderate levels, Si effects often become more apparent. For example, in the nanosilicon experiment, the stimulation of SOD and CAT by 1 mM nSi was much greater under 100-150 mM NaCl than under 50 mM NaCl (Kusvuran et al., 2024). However, as salinity continues to increase, growth and yield may still decline substantially. Si can alleviate damage, but it cannot completely eliminate the effects of severe salinity stress.

Short-term seedling experiments lasting 15-30 d can produce clear physiological responses, but they do not necessarily represent the entire production cycle. Under prolonged salinity stress, Na^+ and Cl^- continue to accumulate, while flowering, pollination, and fruit expansion may also be affected. In a long-term study of two sweet pepper genotypes, Giorio et al. (2020) found that early changes in plant water status were not fully consistent with later yield responses. Future evaluations of Si should therefore distinguish short-term "leaf recovery" from long-term "yield recovery" rather than treating them as equivalent outcomes.

7.3 Genotype and growth environment

Genotype is likely to be an underappreciated moderator of Si effectiveness. Altuntas et al. (2018) found that the salt-sensitive cultivar 'Demre' responded strongly to Si under 75 mM NaCl, whereas the salt-tolerant cultivar 'Karaisali' still showed a clear benefit under 150 mM NaCl. Antioxidant studies have also shown that CAT, APX, and related responses differ between pepper cultivars exposed to the same Si and salinity treatments (Altuntas et al., 2025). Intrinsic differences in Na^+ exclusion, K^+ retention, and basal antioxidant capacity are all likely to influence the additional benefit that can be obtained from Si application (Figure 3).

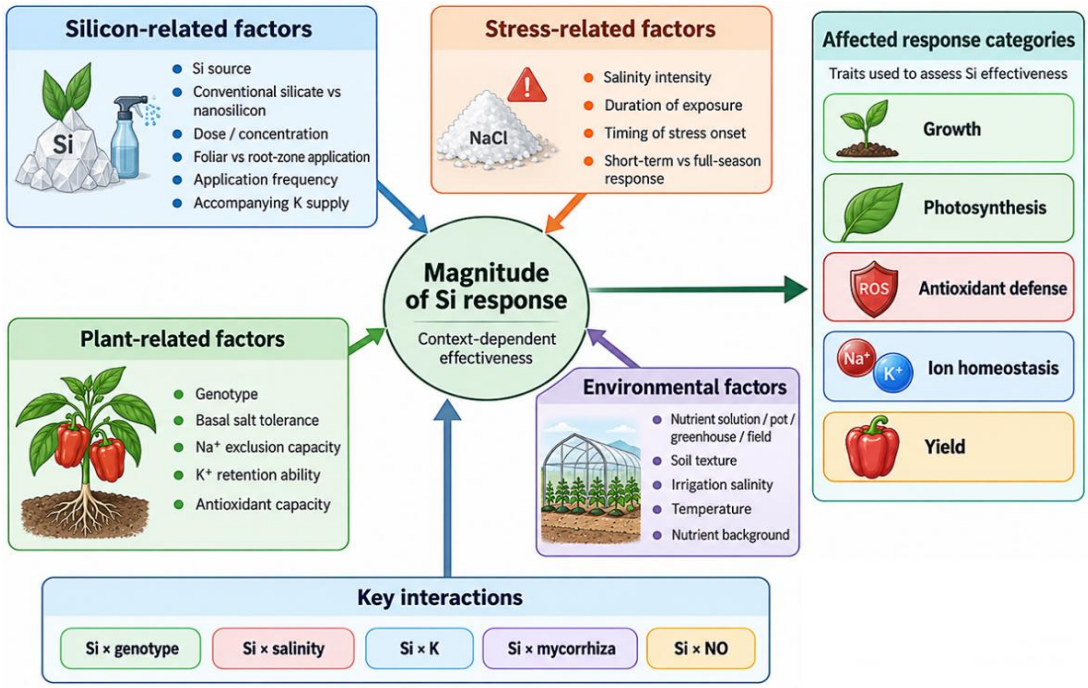


Figure 3 Major moderators of silicon effectiveness in pepper under salinity stress

Image caption: The magnitude of the response to Si is jointly determined by Si source and application characteristics, salinity intensity and duration, genotype, and growth environment. Interactions with nutrients and other treatments, including K, mycorrhizae, and NO, may further modify the observed response. These moderators should therefore be considered when interpreting pooled effects across studies