recent studies also indicate that heat tolerance can to some extent be transferred through grafting, although the effect depends on appropriate matching between rootstock and scion (Biermann et al., 2025).

6 Regulatory Effects of the Protected Environment on High and Stable Tomato Yield

6.1 Effects of temperature regulation on tomato growth, development, and fruit set

Temperature is one of the key environmental factors affecting growth, development, and yield stability in protected tomato production. Tomatoes have different temperature requirements at different growth stages, but overall, their growth, flowering, pollination, and fruit development depend on suitable and stable temperature conditions. Tomatoes generally exhibit good growth and fruiting performance when daytime temperatures are about 18 °C-29 °C with relatively lower nighttime temperatures, whereas excessively high or low temperatures can disrupt plant physiological processes and reduce yield stability (Arshad et al., 2024). Under high-temperature conditions, early plant growth rates may temporarily increase, but pollen viability, pollen germination, and pollen tube growth are often inhibited, resulting in poor pollination, reduced fruit set, and increased flower and fruit drop (Jerca et al., 2024). When the average temperature increases from 14 °C-26 °C, the period from flowering to fruit maturity can be significantly shortened, but excessively high temperatures often lead to smaller fruits and reduced fruit set.

Low temperatures can also limit protected tomato production. Under low-temperature conditions, leaf photosynthesis and assimilate transport capacity decrease, plant growth slows, and flower bud differentiation may be inhibited, leading to delayed flowering (Adams et al., 2001). In early spring or winter protected cultivation, excessively low night temperatures often impair reproductive growth and reduce fruit marketability. In addition to average temperature, microclimatic differences within the greenhouse can also influence yield performance. Studies show that even when the difference in average daily temperature within the same greenhouse is only about 3 °C, noticeable differences in plant growth rate and fruit truss weight may occur (Šalagovič et al., 2024). Furthermore, maintaining temperatures around 18 °C-22 °C during flowering and early fruit set is more favorable for inflorescence productivity (Jerca et al., 2024), while maintaining relatively higher air temperature and suitable root-zone temperature during the seedling stage promotes root development and leaf area formation.

6.2 Effects of light intensity and photoperiod on photosynthesis and yield formation

Light is the primary energy source driving photosynthesis and dry matter accumulation in tomatoes, and therefore directly influences the potential yield of protected tomatoes. Light intensity, daily light integral (DLI), and light distribution within the canopy all affect leaf carbon assimilation capacity and fruit development. Although light distribution in large greenhouses is relatively uniform, spatial variation still leads to differences in plant growth and yield; plants located in areas with better light conditions generally achieve higher yields (Šalagovič et al., 2024). Adequate and sufficient light promotes photosynthesis and dry matter accumulation and provides the energy required for flowering and fruit enlargement. The optimal light intensity for inflorescence development and high yield formation in cherry tomato is about 360-384 $W \cdot m^{-2}$, whereas insufficient light reduces inflorescence number and fruit set efficiency (Jerca et al., 2024). Under winter greenhouse conditions, increasing light intensity can also significantly promote plant growth and yield formation (Arshad et al., 2024).

When natural light is insufficient, artificial supplemental lighting has become an important technology in protected tomato production. A meta-analysis showed that LED supplemental lighting can increase greenhouse tomato yield by about 40% on average and significantly enhance photosynthetic capacity and chlorophyll content. Inter-canopy lighting not only increases total radiation input but also improves light distribution within the canopy, enhancing light-use efficiency of lower leaves and promoting uniform fruit development. In addition, photoperiod and the allocation of light-dark cycles may also influence yield formation. Under the same daily light integral, extending the light-dark cycle may increase yield in some cases; however, when the total light input remains constant, changes in photoperiod have a limited effect on yield. Therefore, in protected tomato production, ensuring sufficient daily light integral (DLI) and properly scheduling supplemental lighting periods is generally more important (Shibaeva et al., 2024).